Title: EFFICIENT CONTROL ALGORITHM FOR START-STOP OPERATION OF REFRIGERATION UNIT POWERED BY AN ENGINE

Abstract: A refrigeration unit (10) and a method for controlling same during start-stop operation is provided. The refrigeration unit may include an engine (12) operable between at least a low engine speed and a high engine speed, a compressor (16) operatively coupled to the engine, and a controller (20) operatively coupled to each of the engine and the compressor. The controller may be configured to operate the engine (12) at a reduced low speed during a delay period, extend the delay period based on the reduced low speed, increase a displacement capacity of the compressor based on the extended delay period, and operate the engine at a reduced high speed.
EFFICIENT CONTROL ALGORITHM FOR START-STOP OPERATION OF A REFRIGERATION UNIT POWERED BY AN ENGINE

FIELD OF THE DISCLOSURE

[0001] The present disclosure generally relates to refrigeration units, and more particularly, relates to a control scheme of a refrigeration unit being powered by an engine.

BACKGROUND OF THE DISCLOSURE

[0002] Refrigeration systems are generally used to maintain a relatively low temperature within a designated area. Refrigeration systems serve to remove heat from a substantially enclosed area and transfer the heat to an environment external to the enclosed area. Refrigeration systems are commonly used in association with residential and commercial food refrigerators, air-conditioning units in homes and automobiles, as well as with refrigerated cargos of ships and trucks. Mobile refrigeration systems used to condition frozen and perishable loads in cargo spaces of trucks and trailers are referred to as transport refrigeration units.

[0003] A typical transport refrigeration unit is associated with transportable cargo or an insulated trailer. Such mobile transport refrigeration units are generally powered by a mobile power source, such as a combustion engine, to cool the temperature within a trailer to a desired setpoint temperature or a range thereof. In addition to cooling, transport refrigeration units must also be sufficiently capable of maintaining a specific range of trailer temperatures even in the presence of contrasting ambient temperatures and load conditions. This can be accomplished by continuously driving the compressor off of the engine. However, continuous operation of the compressor and the engine also requires continuous consumption of fuel.
Accordingly, some transport refrigeration units provide a start-stop mode of operation as a fuel efficient alternative to the continuous mode of operation. Specifically, the engine is operated at a low engine speed for a predetermined runtime or delay period so as to operate the associated compressor and provide a first stage of cooling. After the delay period, the engine is operated at a high engine speed to drive the compressor during a second stage of cooling. Once the trailer is cooled to the desired setpoint temperature during the second cooling stage, the engine is shut off until further cooling is required. While such modes of operation provide some conservation of fuel, there is still room for improvement.

Start-stop modes of operating a transport refrigeration unit provide some conservation of fuel with respect to continuous modes of operation. However, the processes within currently existing start-stop operations are not optimized for efficiency. For example, each of the low and high engine speeds can be modified to conserve more fuel and/or to perform better cooling. The runtime between the first and second stages of cooling, or the duration of the delay period, can also be modified to compensate for any reduction or increase in the low and high engine speeds. Additionally, the displacement capacity of the compressor can be modified to further compensate for any changes in the low and high engine speeds. Currently existing implementations of start-stop operations do not take such modifications into consideration.

The disclosed systems and methods are directed at overcoming one or more of the deficiencies set forth above.

**SUMMARY OF THE DISCLOSURE**

In accordance with one aspect of the disclosure, a method for controlling a refrigeration unit being powered by an engine and having a compressor is provided. The
method may operate the engine at a reduced first speed during a delay period, extend the delay period based on the reduced first speed, increase a displacement capacity of the compressor based on the extended delay period, and operate the engine at a reduced second speed, wherein the reduced first speed may be less than the reduced second speed.

[0008] In accordance with another aspect of the disclosure, a method for controlling a refrigeration unit being powered by an engine and having a compressor during start-stop operation is provided. The method may start the engine to a reduced low engine speed during a delay period, extend the delay period based on the reduced low engine speed, increase a displacement capacity of the compressor based at least partially on the reduced low engine speed and the extended delay period, operate the engine at a reduced high engine speed once the extended delay period is exceeded, and stop the engine once a setpoint temperature is reached.

[0009] In accordance with yet another aspect of the disclosure, a refrigeration unit is provided. The refrigeration unit may include a variable speed engine operable between at least a low engine speed and a high engine speed, a compressor operatively coupled to the engine, and a controller operatively coupled to each of the engine and the compressor. The controller may be configured to operate the engine at a reduced low speed during a delay period, extend the delay period based on the reduced low speed, increase a displacement capacity of the compressor based on the extended delay period, and operate the engine at a reduced high speed.

[0010] Other advantages and features will be apparent from the following detailed description when read in conjunction with the attached drawings.

**BRIEF DESCRIPTION OF THE DRAWINGS**
FIG. 1 is a diagrammatic view of one exemplary refrigeration unit being powered by an engine and constructed in accordance with the teachings of the present disclosure;

FIG. 2 is a graphical view of a fuel map that may be referenced during start-stop operation of a transport refrigeration unit; and

FIG. 3 is a flow chart illustrating an exemplary control algorithm for controlling start-stop operation of a transport refrigeration unit.

It should be understood that the drawings are not necessarily to scale and that the disclosed embodiments are sometimes illustrated diagrammatically and in partial views. In certain instances, details which are not necessary for an understanding of the disclosed methods and systems or which render other details difficult to perceive may have been omitted. It should be understood, of course, that this disclosure is not limited to the particular embodiments illustrated herein.

DETAILED DESCRIPTION OF THE DISCLOSURE

Turning to FIG. 1, a schematic diagram of an exemplary refrigeration unit 10 is provided. As shown, the refrigeration unit 10 may be powered by an engine 12, for example, a variable speed combustion engine, or any other suitable power source commonly used in the art and operable at variable speeds. Furthermore, the refrigeration unit 10 may be implemented as a transport refrigeration unit, or any other type of refrigeration unit that may receive power from an engine or a comparable power source.

Still referring to FIG. 1, an output of the engine 12 may be operably coupled to a generator 14 via drive belts, or the like. Specifically, the torque that is generated by the engine 12 may be used to at least partially rotate a rotor of the generator 14 within an
associated stator so as to generate power in the form of, for example, alternating current (AC).

The refrigeration unit 10 may further include a compressor 16 having a motor 18. An output of the generator 14 may be operatively coupled to the compressor motor 18 and configured to supply electrical power thereto. The refrigeration unit 10 may additionally include a controller 20 that is in electrical communication with each of the engine 12 and the compressor 16 and configured to, for example, control engine speed, compressor displacement, and the like.

[0017] The refrigeration unit 10 of FIG. 1 may further provide a refrigerating cycle 22 through which a refrigerant may flow and draw heat away from a desired cooling area. In addition to the compressor 16, the refrigerating cycle 22 may include a condenser 24, an expansion valve 26, and an evaporator 28. More specifically, the condenser 24 may be coupled to the expansion valve 26, which may further be coupled to the evaporator 28. The compressor 16 may be coupled to each of the condenser 24 and the evaporator 28. The refrigerant may include, for example, fluorinated carbons, chlorinated carbons, brominated carbons, carbon dioxide, ammonia, ethane-based refrigerants, methane-based refrigerants, water, or any other refrigerant commonly used in the art for the purposes of absorbing and transferring heat. Refrigerants may absorb heat by evaporating and changing its state from a liquid to a gas, for example, at low temperatures and pressures, and release heat by condensing and changing its state from a gas back to a liquid, for example, at higher temperatures and pressures. In the particular embodiment of FIG. 1, the compressor 16 may serve to compress and discharge the high pressure refrigerant through the refrigerating cycle 22. The discharged refrigerant may flow through the condenser 24 and to the expansion valve 26. The expansion valve 26 may then lower the pressure of the refrigerant as the
refrigerant flows through the expansion valve 26 and into the evaporator 28. The refrigerant may then be collected back into the compressor 22 to be passed through the refrigerating cycle 22 again.

[0018] The refrigeration unit 10 of FIG. 1 may operate in any one of a variety of operating modes in order to achieve a desired setpoint temperature in the least amount of time with the least consumption of fuel. Moreover, the controller 20 may be configured to strategically vary the output speed of the engine 12, and thus, the power supplied to the compressor 16 based on the desired setpoint temperature and the amount of cooling that is required to reach the setpoint temperature. During a continuous mode of operation, for example, the controller 20 may initially engage the engine 12 and the compressor 16 at full load so as to quickly reduce the temperature to the desired setpoint. Once the setpoint temperature is reached, the controller 20 may then operate the engine 12 and the compressor 16 at part load to maintain the setpoint temperature or an approximate range thereabout. During a start-stop mode of operation, for example, the controller 20 may initially start the engine 12 and engage a low engine speed for a predetermined delay period. After the delay period, the controller 20 may operate the engine 12 at a high engine speed to continue cooling until the setpoint temperature is reached. Once the setpoint temperature is achieved, the controller 20 may stop operating the engine 12 until, for instance, additional cooling is required.

[0019] Turning now to FIG. 2, a fuel map 30 characterizing the consumption of fuel during a start-stop mode of operating a refrigeration unit 10 is provided. In particular, the fuel map 30 may provide information pertaining to, for example, the resulting fuel consumption and efficiency of an engine 12 operating at different engine speeds and for different runtimes or delay periods. As shown, a reduction in engine speed may improve the immediate efficiency
of the refrigeration unit 10. However, at reduced engine speeds, the engine 12 and the compressor 16 may need to be operated longer, and thus, consume more fuel in order to reach the setpoint temperature. Accordingly, in order to effectively decrease overall fuel consumption and increase the efficiency of the refrigeration unit 10, an optimum point 32 may be assessed from the fuel map 30. Moreover, the optimum point 32 may be indicative of a combination of new reduced engine speeds and new extended runtimes or delay periods at which start-stop operations should be performed in order to realize more efficient but uncompromised cooling for a particular refrigeration unit 10.

[0020] Based on such assessments of a fuel map 30, the controller 20 may be able to implement changes to the engine speed and/or the runtime or delay period of the start-stop process so as to minimize fuel consumption and optimize overall efficiency. For example, the controller 20 may be adapted to operate the engine 12 at slower or reduced engine speeds to reduce fuel consumption, and further, extend the delay period to allow the compressor 16 more time to cool to the desired setpoint temperature. The controller 20 may also be configured to change and/or adapt to a change in the displacement capacity of the associated compressor 16 so as to further compensate for the reduced engine speeds and to minimize the time required to reach the desired setpoint temperature. For example, the controller 20 may be configured to increase the effective displacement capacity of the compressor 16 by increasing the operating frequency thereof, and thus, increasing the rate at which refrigerant is compressed and cycled. The controller 20 may also be adapted to operate a compressor 16 with a physically larger displacement capacity.

[0021] Referring to FIG. 3, a flow chart of an exemplary control method or algorithm, for example, by which a controller 20 may be configured to operate a refrigeration unit during a
start-stop operation, is provided. As shown, the controller 20 may initially start the engine 12 and operate the engine 12 at a new, reduced low engine speed so as to conserve fuel. The reduced low engine speed as provided by the controller 20 may correspond to, for example, a reduction of approximately 13% or more in the low engine speed. The controller 20 may maintain the reduced low engine speed for a longer runtime, or for an extended delay period, so as to at least partially compensate for the reduced low engine speed. To further compensate for the reduced low engine speed and to minimize the duration of the extended delay period, the controller 20 may effectively provide for an increase in the displacement capacity of the associated compressor 16. For example, the controller 20 may operate the compressor 16 at an increased operating frequency and/or operate a compressor 16 of a larger displacement capacity. The increased displacement capacity of the compressor 16 may correspond to, for example, an increase of approximately 15% or more. Once the extended delay period is exceeded, the controller 20 may engage the engine 12 to operate at a new, reduced high engine speed. As with the reduced low engine speed, the reduced high engine speed may also correspond to, for example, an increase of approximately 13% or more. The controller 20 may maintain the engine 12 at the reduced high engine speed until the setpoint temperature is reached. Once the temperature substantially reaches the desired setpoint, the controller 20 may stop the engine 12 to conserve fuel. Additionally or optionally, the controller 20 may further monitor the temperature within the cargo area of the refrigeration unit 10 and automatically restart the start-stop operation if the temperature exceeds the setpoint or an acceptable range thereof.

While only certain embodiments have been set forth, alternatives and modifications will be apparent from the above description to those skilled in the art. These and other
alternatives are considered equivalents and within the spirit and scope of this disclosure and
the appended claims.
WHAT IS CLAIMED IS:

1. A method for controlling a refrigeration unit being powered by an engine and having a compressor, the method comprising the steps of:
   operating the engine at a reduced first speed during a delay period;
   extending the delay period based on the reduced first speed;
   increasing a displacement capacity of the compressor based on the extended delay period; and
   operating the engine at a reduced second speed, the reduced first speed being less than the reduced second speed.

2. The method of claim 1 further comprising the step of stopping the engine once a setpoint temperature is reached.

3. The method of claim 1, wherein the engine is operated at the reduced second speed only once the extended delay period is exceeded.

4. The method of claim 1, wherein each of the reduced first and second speeds is decreased by at least 13%.

5. The method of claim 1, wherein the increase in the displacement capacity of the compressor is based on an increase in a physical size of the compressor.

6. The method of claim 1, wherein the increase in the displacement capacity of the compressor is based on an increase in an operating frequency of the compressor.

7. The method of claim 1, wherein the displacement capacity of the compressor is increased by at least 15%.
8. The method of claim 1, wherein one or more of the reduced first speed, extended delay period, displacement capacity and the reduced second speed is determined based on a fuel map of the engine.
9. A method for controlling a refrigeration unit being powered by an engine and having a compressor during start-stop operation, the method comprising the steps of:

starting the engine to a reduced low engine speed during a delay period;

extending the delay period based on the reduced low engine speed;

increasing a displacement capacity of the compressor based at least partially on the reduced low engine speed and the extended delay period;

operating the engine at a reduced high engine speed once the extended delay period is exceeded; and

stopping the engine once a setpoint temperature is reached.

10. The method of claim 9, wherein each of the reduced low and high engine speeds is decreased by at least 13%.

11. The method of claim 9, wherein the increase in the displacement capacity of the compressor corresponds to one or more of an increase in a physical size of the compressor and an increase in an operating frequency of the compressor.

12. The method of claim 9, wherein the displacement capacity of the compressor is increased by at least 15%.

13. The method of claim 9, wherein one or more of the reduced first engine speed, extended delay period, displacement capacity and the reduced second engine speed is determined based on a fuel map of the engine.
14. A refrigeration unit, comprising:

a variable speed engine operable between at least a low engine speed and a high engine speed;

a compressor operatively coupled to the engine; and

a controller operatively coupled to each of the engine and the compressor, the controller being configured to operate the engine at a reduced low speed during a delay period, extend the delay period based on the reduced low speed, increase a displacement capacity of the compressor based on the extended delay period, and operate the engine at a reduced high speed.

15. The refrigeration unit of claim 14 further comprising a condenser operatively coupled to the compressor, an expansion valve operatively coupled to the condenser, and an evaporator operatively coupled to the expansion valve.

16. The refrigeration unit of claim 14, wherein the controller is configured to stop the engine once a setpoint temperature is reached.

17. The refrigeration unit of claim 14, wherein the controller decreases each of the reduced low and high engine speeds by at least 13%.

18. The refrigeration unit of claim 14, wherein the controller increases the displacement capacity of the compressor based on one or more of an increase in a physical size of the compressor and an increase in an operating frequency of the compressor.

19. The refrigeration unit of claim 14, wherein the controller increases the displacement capacity of the compressor by at least 15%.
20. The refrigeration unit of claim 14, wherein one or more of the reduced low speed, extended delay period, displacement capacity and the reduced high speed is determined based on a fuel map of the engine preprogrammed into the controller.
FIG. 1

- Engine
- Generator
- Controller
- Compressor
- Motor
- Condenser
- Expansion Valve
- Evaporator
Start engine

Operate engine at reduced low engine speed

Extend delay period

Delay period exceeded?
- No
- Yes
  Increase displacement capacity of compressor

Operate engine at reduced high engine speed

Setpoint temperature reached?
- No
- Yes
  Stop engine

FIG. 3
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched: (classification system followed by classification symbols)
B60H F02D F25B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>EP 1 G46 543 A2 (CARRIER CORP [US]) 25 October 2000 (2000-10-25) paragraph [0014], paragraph [0023]; figures 1, 2, 4</td>
<td>1-29</td>
</tr>
<tr>
<td>X</td>
<td>US 4 926 651 A (NOGUCHI ICHI RO [JP]) 22 May 1990 (1990-05-22) claim 1; figure 2</td>
<td>1, 9, 14</td>
</tr>
<tr>
<td>X</td>
<td>US 5 331 821 A (HANSON JAY L [US] ET AL) 26 July 1994 (1994-07-26) column 1, line 24 - column 5, line 19; figure 1a</td>
<td>1, 9, 14</td>
</tr>
</tbody>
</table>

Further documents are listed in the continuation of Box C.

* Special categories of cited documents:

* A* document defining the general state of the art which is not considered to be of particular relevance
* B* earlier document but published on or after the international filing date
* L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
* O* document referring to an oral disclosure, use, exhibition or other means
* P* document published prior to the international filing date but later than the priority date claimed
* T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
* X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
* Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
* Z* document member of the same family

Date of the actual completion of the international search 7 March 2012

Date of mailing of the international search report 15/03/2012

Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Potentiebaan 2 NL - 2280 HV Rijswijk Tel: (+31-70) 340-2040, Fax: (+31-70) 340-3016

Authorized officer: Gumbel, Andreas
<table>
<thead>
<tr>
<th>Patent document cited in search report</th>
<th>Publication date</th>
<th>Patent family member(s)</th>
<th>Publication date</th>
</tr>
</thead>
<tbody>
<tr>
<td>ES 2272234 T3</td>
<td>01-05-2007</td>
<td>ES 2272234 T3</td>
<td>01-05-2007</td>
</tr>
<tr>
<td>ES 2334049 T3</td>
<td>04-03-2010</td>
<td>ES 2334049 T3</td>
<td>04-03-2010</td>
</tr>
<tr>
<td>ES 2373572 T3</td>
<td>06-02-2012</td>
<td>ES 2373572 T3</td>
<td>06-02-2012</td>
</tr>
<tr>
<td>US 492665 1 A</td>
<td>22-05-1990</td>
<td>JP H01 1528 19 U</td>
<td>20-10-1989</td>
</tr>
<tr>
<td>US 492665 1 A</td>
<td>22-05-1990</td>
<td>US 492665 1 A</td>
<td>22-05-1990</td>
</tr>
<tr>
<td>US 533 182 1 A</td>
<td>26-07-1994</td>
<td>NON E</td>
<td></td>
</tr>
</tbody>
</table>