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Simulation and validation of a hybrid-power gas engine heat pump

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ABSTRACT

Hybrid-power gas engine heat pump (HPGHP) combines hybrid power technology with gas engine heat pump, which can keep the gas engine working in the economical zone. In this paper, a steady-state model of the HPGHP in heating condition has been established, the optimal torque curve control strategy is proposed to distribute power between the gas engine and battery pack. The main operating parameters of the HPGHP system are simulated on Matlab/Simulink and validated by experimental data, such as operating temperature, coefficient of performance (COP), fuel-consumed rate, etc. Heating capacity and COP of the heating pump system are validated under different ambient temperatures and water flow rates. The simulation and experiment results shows acceptable agreement, the maximum difference is respectively 8.9%, 5.9%, 9.5% and 8.2% for engine torque, motor torque, reclaimed heat and fuel-consumed rate. Based on the simulation results, HPGHP has the lowest fuel-consumed rate of 283 g $(kWh)^{-1}$ at engine speed of 3000 rpm; the PER of HPGHP system is about 15.9% and 11.4% higher than the GHP under the same load in Mode C and D.

Simulation et validation d'une pompe à chaleur à moteur à gaz

Mots clés : Pompe à chaleur à moteur à gaz hybride ; Modèle de régime permanent ; Stratégie optimale de régulation de torque ; Validation d'expérience ; Facteur d'énergie primaire

1. Introduction

The last few years have seen a growing interest in the heat pump driven by a gas-engine (GHP). This is partially due to its energy saving achieved by using a high performance natural gas engine to drive the compressor with an efficient reverse cycle (Zhao et al., 2007), which can control the temperature and humidity of the room. The GHP is driven directly by a gas engine instead of an electric motor, losses attributed to the

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Nomenclature

A	the area [m^2]
g_e	the fuel consumption of gas engine [g $(kWh)^{-1}$]
H_f	heat value of the fuel [kJ kg^{-1}]
h	enthalpy of refrigerant [kJ kg^{-1}]
I	current [A]
m	mass flux [g s^{-1}]
N	rotation speed [rpm]
Nu	Nusselt number
P	pressure [Pa]
Pr	Prandtl number
Q	heat transfer rate [kW]
Re	Reynolds number
r	transmission ratio
T	torque [N·m]
t	temperature [°C]
U	voltage [V]
W	out power [kW]
ρ	density [kg m^{-3}]
ν	specific volume [m^3 kg^{-1}]
η	efficiency
η_e	the thermal efficiency of the gas engine
η_{em}	the transmission efficiency between gas engine and motor
η_{bp}	the transmission efficiency of the belt pulley

Subscripts

am	ambient
b	the battery pack
c	the compressor
ch	the condition of charging
d	the condition of discharging
e	the engine
ev	the expansion valve
f	The gas fuel
in	the inlet
l	liquid
m	the motor
max	the maximum value
min	the minimum value
out	the outlet
opt	the point on the optimal curve
re	the refrigeration
rec	heat recovery
se	The secondary fluid of condenser and evaporator
v	vapor

Abbreviations

COP	coefficient of performance
GHP	gas engine heat pump
HPGHP	hybrid-power gas engine heat pump
PER	primary energy ratio
SOC	the state of charge

production and transport of electricity are eliminated (Brenn et al., 2010). However, the gas engine's working conditions should frequently change to satisfy the variation of demand load, and then the gas engine may deviate from its economical zone of maximum efficiency and minimum emissions, which will result in poor stability of the gas engine, lower thermal efficiency, and heavier emission (Li et al., 2007).

To solve this problem, air conditioning and refrigeration laboratory from Southeast University has developed a hybrid-power gas engine heat pump (HPGHP) air conditioning system. The HPGHP system combines the hybrid-power technology with gas heat pump technology, the gas engine and battery pack are the power sources. An optimal matching of the two powers can keep the engine operating in fuel economical zone. At the same time, it can reduce system exhaust emissions and improve fuel economy (Li et al., 2005, 2006). The HPGHP has superior performance with maximum and minimum thermal efficiencies of 37% and 27%, respectively, while those of GHP system are 33% and 22% (Li et al., 2007). Fuel conversion efficiency and life cycle assessment were used to analyze energy-saving effect and environment benefit of a novel HPGHP, the results show that the fuel conversion efficiency under different operating conditions of HPGHP is higher than conventional GHP under the same load (Wang et al., 2013a). Jieyue Wang et al. (Wang et al., 2013b) have established a steady-state model of the coaxial parallel-type drive system to discuss the matching relations between the drive system and the dynamic load of the compressor, and established energy management scheme of battery pack.

For a comprehensive, in-depth understanding of operating characteristics of the HPGHP, theoretical analysis and simulation of the system is necessary. Thermal model of the HPGHP in heating mode is established through combining models of major components and simultaneous solution. Then, various important operating parameters of heat pump cycle such as heating capacity, evaporation and condensation temperature, COP, are investigated and analyzed in the proposed model. The models are validated by experimental data; it shows acceptable agreement between the simulation and experiment results. At last, the significances of this model are discussed.

2. Description of the HPGHP system

Fig. 1 shows the working principle of the HPGHP system. The whole system can be divided into three parts: the drive system, heat pump system and heat recovery system.

The drive system mainly consists of gas engine, lead-acid batteries, motor and other auxiliary devices. The main parameters of the drive system are shown in Table 1. The main power source is the gas engine, and the auxiliary power is the battery pack. The engine and motor connect to the main shaft by clutches, and drive the compressor through belt. The battery connects to the motor through electrical connection. Power distribution is achieved mainly through the gearbox and clutch. The motor and gas engine can not only drive the compressor together in parallel, but also can drive individually.