RESEARCH ON INTEGRATION OF VAPOR CYCLE/LIQUID-COOLED REFRIGERATION SYSTEM FOR HELICOPTERS

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Abstract

Some proposal has been researched on the integration of vapor cycle/liquid-cooled refrigeration system for helicopters. According to mathematic models of system components, the simulation model of this system has been established, heat loads of vapor cycle refrigeration system and lubricant oil system have been removed by the heat sink of fuel and liquid-cooled approaches. The system simulation based on MATLAB/SIMULINK general simulation platform is valuable and significant for integrated system optimization as well as design of system components.

1 Introduction

Helicopters are generally powered by turbo-shaft engines, bleed air flow rate should be decreased as long as possible for helicopters with severe weight demand and severe climate conditions, compared with fixed wing aircrafts. Moreover, helicopter cabins are not pressurized usually because they are not sealed, meanwhile, there is no need to adjust the pressure of bleed air for environmental control system (ECS) at lower flight height. However, helicopters with continuous increase in heat loads of avionics will demand more and more refrigerating capability for ECS, as cruising speeds of helicopters are getting faster and faster.

Environmental control systems were adopted abroad on helicopters in 1960s [1]. Belgium, Korea and Japan are all developing new types of civil helicopters besides some other countries such as America, Russia and Canada. Main helicopter companies of European countries have put forward that helicopters should meet flight needs for whole day climates [2]. With continuous increase of high power and high density avionics on helicopters, cool air source, provided for vapor cycle system by a fan which is driven by electricity or hydraulic pressure, cannot obviously suit for the change of flight altitude and velocity as well as flight conditions, therefore, the integration of vapor cycle refrigeration system and liquid-cooled system is to be developed to meet future demands for increasing development of helicopters.

Research has been made in this paper on the integration of vapor cycle refrigeration system (VCS), fuel system, liquid-cooled cycle system and lubricant oil system, in order to solve dynamic coupling problems of these various subsystems. It has been put forward that vapor cycle/liquid-cooled refrigeration system (VCLCS) can be used as a backup proposal for environmental control systems on helicopters.

2 Integrated Concept for VCLCS

2.1 Scheme Suggestions

Air cycle refrigeration system （ACS）or VCS has already been used successfully as one project of helicopter ECS at present. However, there is moisture or free water at the exit of simplified ACS with simple structure and light weight, furthermore, this system is influenced directly by bleed pressure, overspeed of air cycle machine could cause the flight safety for some atmosphere pressure at some altitude. High pressure water separation bootstrap system improves refrigerating capability and reduces bleed airflow of engine because of its water separation to lead to air exit temperature of turbine cooler less than zero degrees Centigrade, but system refrigerating capacity is hard to get larger due to higher bleed air temperature and restriction of bleed airflow of the engine.

VCS without engine bleed has many advantages over ACS for greater coefficient of performance and less fuel weight penalty, in addition, helicopter cabin is not necessary to be pressurized so that VCS can be adopted for outside air of about 20 degrees Centigrade.

However, enough ram air cannot be provided because of lower flight height and smaller flight speed for helicopters, especially while flying at very low speed, hovering or stopping in the air. Air cooled approach for VCS condenser will not be able to meet refrigerating demand for developing helicopters even though motor-driven fan is used.

Only VCS and liquid cooling technology will meet ongoing development need for future helicopters.

2.2 VCLCS Integration

VCLCS mainly consists of VCS, lubricant oil system, liquid cycle system and fuel system. Fuel can be considered as a heat sink of VCLCS to reject heat load of lubrication oil system. Heat load of vapor cycle system is absorbed by linking of liquid cycle system and fuel system with a fuel-liquid heat exchanger. Figure 1 shows the function architecture of this system.

VCS generally consists of an evaporator, a compressor, a condenser and an expansion valve. Refrigerant evaporates in the evaporator with avionics heat loads transported. The refrigerant is changed into gas with high temperature and high pressure by the compressor and then condensed into in the condenser, so that the heat load is transported into liquid cycle subsystem, then the condensed refrigerant is changed into working medium of gas state with low temperature and low pressure after passing through the expansion valve on the over-cooled condition.

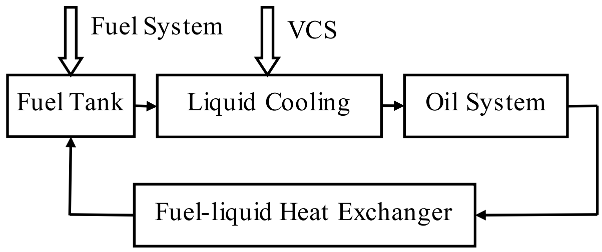

Fig. 1. Function Architecture of the System

Liquid cooling is an indirect cooling approach, which is adopted to cool avionics with coolant of liquid state [3], heat loads of VCS and lubricant oil system can be rejected by fuel heat sink.

Liquid-cooled cycle system is adopted to achieve effective thermal transport into coolant, so that heat loads of avionics can be transported into fuel through the fuel-liquid heat exchanger. The mass flow rates of working fluids are controlled with booster pumps.

Two or more sets of fuel systems, supplying fuel independently or intercrossing fuel supply, are considered as fuel system project of helicopters, as a result, fuel will be possible to be an effective heat sink. VCS and lubricant oil system are connected via fuel cycle to achieve optimal system integration, while making use of fuel heat sink at the most.

Three lubricant oil system concepts have to be considered as self-contained oil system, partially self-contained oil system or airframe supported oil system [4]. Self-contained oil system is considered as an integrated proposal in this paper to avoid interfacing engine and airframe. Heat load of heat generating gear unit of helicopter engine can be removed more effectively by fuel rather than by either an electric fan and a heat exchanger or a compressor mechanically driven by the helicopter gear box.

If VCS and liquid-cooled system are integrated in physics and function, system performance will be promoted and cost as well as fuel weight penalty will be reduced despite increased design complexity.

3 VCLCS Simulation

3.1 Selection of System Working Mediums

VCS is mainly composed of an evaporator, a scroll compressor, a condenser and an expansion valve. The first step of modeling is to select suitable refrigerant as working medium for VCS. At present, refrigerant R-12，R-114 or R134a could be suggested. Refrigerant R134a has been chosen in this paper.

The key of system integration is fuel as a heat sink, fuel cycle mainly depends on its thermal stability and specific heat. Fuel JP-4，JP-5 or JP-10 [5] were used as heat sink on aircrafts abroad, they are suited for aircrafts with Mach 2-3. Fuel RP-3, ever used in some measuring test stand for fuel flow rate in China, is similar to fuels JP-4 and JP-5 in physical characteristics, so the conventional fuel RP-3 is considered in the paper.

PAO (Polyalphaolefin), a fluid coolant, is used on aircrafts abroad as working liquid for its high thermal conductivity and insulation [6]. It is also feasible for an anti-freeze liquid to be a coolant for helicopter ECS, so VCS heat load can be transported into fuel system via this kind of coolant.

Lubricant oil can obviously get higher temperature after passing through heat generating parts like the engine gearbox unit under the drive of oil pump, then it returns to the lubricant oil tank after transporting amount of heat into fuel through a fuel-oil heat exchanger.

3.2 Setting Up of Mathematical Model of Simulation

Simulation research on VCS, originating in 1970s, has developed from steady-state design into dynamic one since 1980s. Steady-state parameter models of VCS have been set up because of simulation of system level for helicopters in the paper.

Mass flow rate G_R for VCS refrigerant:

$$G_R=Q_0/q_0 \qquad (1)$$

where Q_0 is heat load, q_0 is refrigerating capacity for unit refrigerant.

Inlet flow rate is equal to outlet flow rate for scroll compressor that abides by the conservation of energy as below:

$$h_{out1}=h_{in1}+W \qquad (2)$$

where h_{out1} and h_{in1} are outlet and inlet specific enthalpies of the compressor respectively, W is work for unit refrigerant.

Expansion valve can be treated as steady state with thermal isolating expansion for its small time constant.

$$h_{in2}=h_{out2} \qquad (3)$$

where h_{in2} and h_{out2} are inlet and outlet specific enthalpies of expansion valve respectively.

Flow rate through expansion valve is flow rates of condenser outlet and evaporator inlet. Below is the conservation of energy for various kinds of heat exchangers (HX):

$$G_r(h_{in3}-h_{out3})=G_l(h_{out4}-h_{in4}) \qquad (4)$$

where G_r and G_l are mass flow rates of HX hot side and cold side respectively, h_{in3} and h_{out3} are inlet and outlet specific enthalpies for HX hot side respectively, h_{in4} and h_{out4} are inlet and outlet specific enthalpies for HX cold side respectively.

The operation of each pump for every cycle loop depends on characteristic curve of each pump and system pipelines. Pressure rise and input power are treated to be the functions of volume flow rate and input conditions of simulating analysis of cycle pumps. To simplify the heat transfer calculation of pumps during simulating analysis, corresponding heat loads for pumps are added to heat generating parts of cycle systems.

3.3 Setting up of simulation software platform

According to operational principle of VCLCS, simulation software platform has been set up, simulation research has been made to support system optimization as well as component design and to explore dynamic relations of various subsystems so as to obtain optimum integrated result of VCLCS for helicopters.

Component models of VCLCS have been established based on modularization, input and output of each module are defined and shown in accordance with unified standard to modify and test parameters of modules. Developed simulation software meets requirements for real-time simulation. Below is function module diagram of VCLCS simulation as shown in Figure 2. Figure 3 shows the system simulating design.

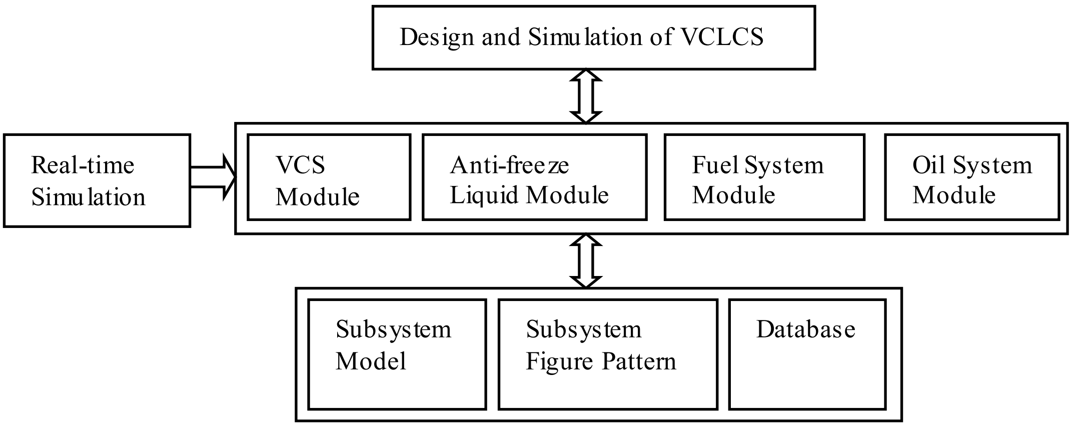

Fig. 2. Function Module Diagram of System Simulation

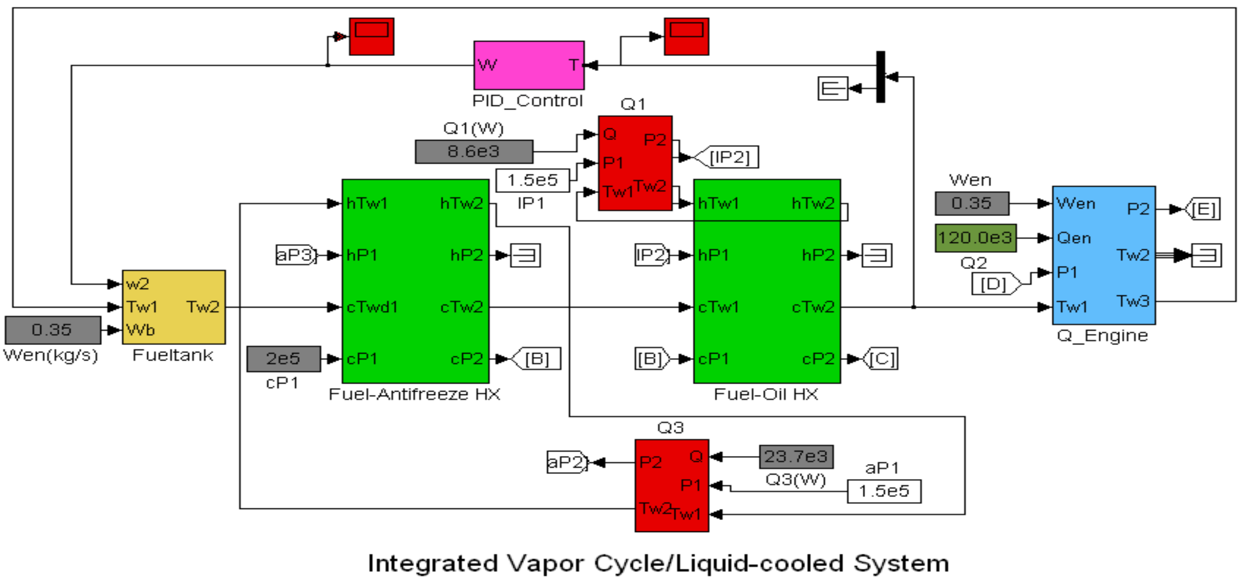

Fig. 3. System Simulating Design

cooled system, fuel system, etc., the results of system simulation are shown as Figure 4 to Figure 6 based on MATLAB/SIMULINK general simulation platform.

Figure 4 means that the antifreeze liquid temperature change with simulation time meets the refrigerating requirement for VCS, Figure 5 indicates that the fuel temperature changes with

3.4 Simulation computing

Ambient temperature for some helicopter is supposed to be 40 degrees Centigrade, cabin temperature is 27 degrees Centigrade, cabin heat load is 23.7kW, the heat load of lubricant oil system is 120kW.According to simulating system models on the basis of mathematical models of each subsystem such as VCS, liquid-

simulation time so that VCLCS reaches thermal balance effects, Figure 6 shows that the change trend of fuel flow rate shows VCLCS meets the refrigerating requirements for the system by making use of the coupling of fuel heat sink and liquid cooling in the situation of system stability.

In a word, system simulation design has been made to support system optimization as well as component design so as to obtain the optimum integrated result of helicopter VCLCS for future engineering applications.

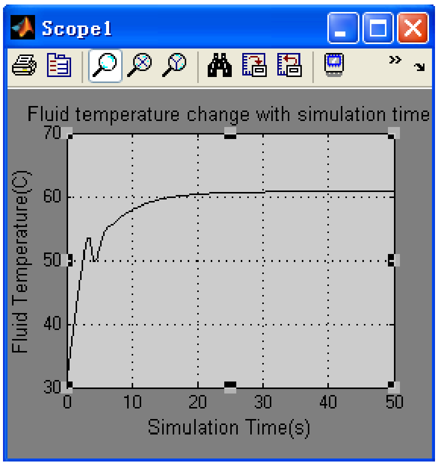

Fig. 4. Liquid Temperature Change Curve

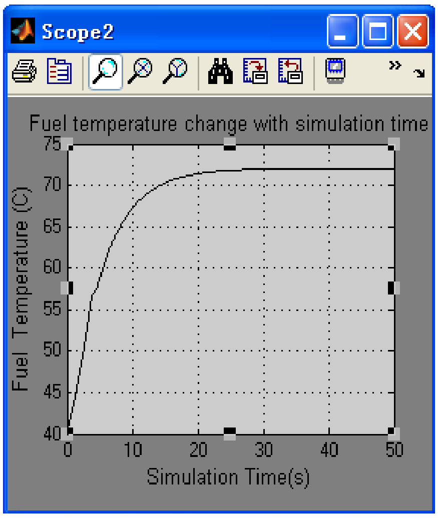

Fig. 5. Fuel Temperature Change Curve

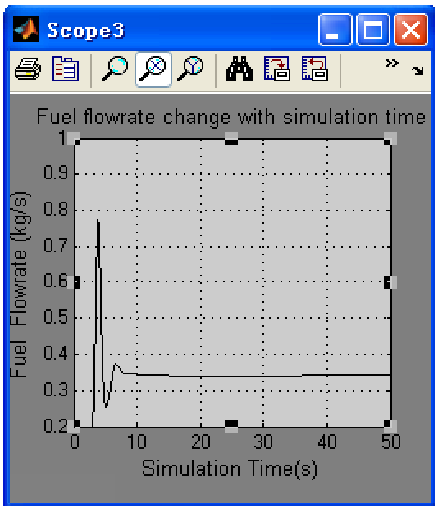

Fig. 6. Fuel flow Rate Change Curve

4 Conclusion

Research has been made on the integration of vapor cycle refrigeration system, fuel system, liquid-cooled cycle system and lubricant oil system, in order to solve the integration and dynamic coupling problems of these various subsystems for helicopters.

General simulation platform called MATLAB/SIMULINK has been used to simulate integrated vapor cycle/liquid-cooled refrigeration system. According to mathematic models of subsystem components, Simulation models of this system have been established to finish simulation and analysis of dynamic system to achieve integrated purposes of system optimization.

The research result in this paper is valuable and significant for helicopter system integration and optimization as well as design of system components. With the development of the helicopter's new technologies, this kind of vapor cycle/liquid-cooled refrigeration system will be put into wide use in the field of future helicopters.

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