State-of-the-art and some considerations on thermal load analysis and thermal management for hydraulic system in MEA

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Abstract: Hydraulic system is an important part in aircraft secondary energy-resource system, its pumping source contains engine-driven pump (EDP) and electrical-motor-driven pump, and it is in charge of safe and reliable power transmission for flight control actuation in the aircraft. The power losses in hydraulic system will inevitably result in the temperature rise of hydraulic system, and which will seriously affect the performances of hydraulic system. Therefore, to cool thermal load and control hydraulic oil temperature in allowable range is necessary. This survey paper reviews the present status of thermal load analysis and thermal management of the aircraft hydraulic system, especially more electric aircraft (MEA), and proposes fuel/hydraulic oil heat exchanger is the more effective heat dissipation component for fuel oil as heat sink be directly burned in burner without the extra cooling cost. Moreover, this paper provides some considerations and thorough analysis on thermal management schemes and actuators in power by wire transmission system of MEA. The main summarised conclusions and proposed considerations have the important practical significances to design and high efficient operation of airborne hydraulic system.

1 Introduction

Hydraulic system is an important part in aircraft secondary energy system. It is responsible for providing and dividing power for actuation of flight control surfaces, landing gear and braking system. Therefore its safety and reliability is very essential to finish a flight mission smoothly [1, 2]. Owing to its advantages such as fast response, steady transmission, and high power-to-weight ratio, aircraft hydraulic system (AHS) has been widely utilised as the flight control actuation for a long time. Its pumping source is engine-driven axial piston pump (primary) and electric-motor-driven axial piston pump (stand by) [3]. With the increasing demand of aircraft performance, the power, pressure and electrification in hydraulic system have been increased accordingly, meanwhile it also brings about the power loss and results in overheat of hydraulic oil and components, and thus severely affects flight safety and reliability [4].

The hydraulic oil is the working medium of the hydraulic system, to keep its normal physical and chemical characteristics is most basic request during the overall flight mission. Its viscosity decreases as its temperature increases [4], and excessive oil temperature may cause deterioration of the hydraulic oil. The hydraulic oil in high temperature range will result in very severe leakage and seal ageing of the hydraulic components, thus the hydraulic actuators of the aircraft cannot operate safely and reliably. Therefore, to control the hydraulic oil in allowable temperature range is very necessary to the flight safety. In order to limit hydraulic oil temperature in allowable range for a specific mission profile, many scientific research institutes had conducted lots studies in recent years.

Hydraulic system in part of commercial aircraft such as A320 adopts hydraulic tank and hydraulic pipes (part of pipes pass fuel tank) to dissipate heat in that most of time is in cruise flight state [4], and Boeing Series commercial aircraft, e.g. B737, additionally adopts fuel/hydraulic oil heat exchanger to dissipate heat for better thermal management [1, 4]. Military aircraft hydraulic system uses fuel/hydraulic oil heat exchanger, hydraulic oil tank and hydraulic pipe to dissipate heat in that most of time is in combat state. With the help of the digital control technology, fuel/hydraulic oil heat exchanger can utilise a part of overall thermal load to help the required fuel burn sufficiently [1, 4–6].

Thermal load is mainly generated by idle power loss and oil leakage in hydraulic components. The components of primary power loss are primary pump such as engine-driven pump (EDP) and EMDP, and servo valve control actuator. With the growing more electric aircraft (MEA) trend, EMDP had served as primary pump (e.g. B787), electro-hydrostatic actuator (EHA) and electric-mechanical actuator (EMA) have been gradually introduced into local flight control actuation such as A380 and B787, and the flight actuation of F-35 almost adopted EHA and EMA. For EHA, the volumetric flowrate control through variable speed motor from flight control computer can obviously reduce power loss of idle and oil leakage. In MEA, engine-driven centralised hydraulic system will be replaced by power-by-wire (PBW) local EHA, EMA [7, 8]. Although EHA based on volumetric control has small power loss, it has no the heat-dissipation of the return pipe, and the thermal management of EHA during its operation has been also carefully addressed.

The goal of this paper is to provide an overview for thermal load analysis and thermal management of the AHS, and some considerations. Firstly, thermal mechanism of AHS will be studied in detail. Then based on the thermal analysis, the considerations and outcomes of thermal management schemes will be discussed thoroughly. Finally, based on the non-similar redundancy reliability, this paper states that a lot of aircrafts still adopt convenient central hydraulic system and PBW hybrid transmission system, and thermal measures are fuel/hydraulic oil heat exchanger, hydraulic oil tank and hydraulic pipe.

2 Thermal load analysis

Aircraft secondary energy system, shown in Fig. 1, which differs from main propulsive power, is made up of electrical, hydraulic
and pneumatic energy system. These subsystems mainly provide the power supply for flight actuation and environment control of aircraft and also provide power for fuel system and lubrication oil system in MEA. During the flight mission, the power loss can inevitably happen and then transform into thermal load [1, 5].

2.1 Power loss and thermal load

Fig. 2 indicates main functions of AHS. Hydraulic system and electrical system are responsible for providing the power supply for flight actuation of the aircraft. This deals with two times energy conversions, and will produce the power losses. Environment control system is in charge of providing the requested working environment for airborne system and cabin. Fig. 3 denotes the power transmission process and power losses of aircraft hydraulic system, and the power losses of AHS are mainly produced by pump and the leakage of the control valve, and valve-opening metering while actuator working, and then is converted to thermal load. The thermal load will seriously affect normal operation of airborne devices when lacking effective cooling equipment [5, 9]. Some thermal load in aircraft hydraulic system usually can be absorbed by hydraulic oil and hydraulic components; others usually can be dumped within airborne equipment bay [4]. The request of the viscosity-temperature needs to control the temperature of hydraulic oil in the reasonable range. Therefore, the thermal load analysis and management scheme should focus on temperature control of hydraulic oil to make it within the proper range.

Aircraft hydraulic system usually consists of EDP and EMDP, servo valve (or direction valve), accumulator, tank, pipe, heat exchanger and hydraulic cylinder and motor etc. Most civil and military aircrafts in service today adopt the centralised hydraulic system [3]. Hydraulic power is extracted from the airframe-mounted accessories drive (AMAD) EDP and EMDP. The pressurised oil output from EDP or EMDP passes long pipe and then acts on actuator working, and then is converted to thermal load. The thermal load will seriously affect normal operation of airborne devices when lacking effective cooling equipment [5, 9]. Some thermal load in aircraft hydraulic system usually can be absorbed by hydraulic oil and hydraulic components; others usually can be dumped within airborne equipment bay [4].

The hydraulic reservoir and heat exchanger are generally located in airborne equipment bay whose temperatures are much lower than engine bay; meantime their thermal inertias are larger than other parts in hydraulic system [4], so thermal load of AHS is mainly absorbed in hydraulic oil tank and heat exchanger. Hydraulic oil flows in hydraulic pipe, and then brings about thermal load related to friction loss. However, considering the fact that the vast majority of hydraulic pipe is located inside the accessories equipment bay, and thermal load can be basically cooled by ambient cooling air. In many cases, the return pipe passes fuel oil tank, and it also cools part thermal load. The throttling loss of the servo valve especially for high-pressure hydraulic system will cause the large thermal load during the actuator operation. As about hydraulic actuator, because it connects with flight control surface and it will be exposed to outside cold air during working period, and its thermal load can be basically mitigated by outside cold air.

2.2 Analysis of thermal load and thermal dynamics

Based on the above discussions, thermal load of AHS depends greatly on its flight mission profile, ambient temperature of the aircraft and the working state of the actuators. The pump in AHS widely adopts axial piston pump with constant pressure variable displacement due to its self-adjusting flowrate according to the flowrate need of the flight mission. For civil aircraft, because most of time is in cruising flight state, the power losses mainly include power loss of the primary pump and the leakage power loss of the valve, and heat-generation problem is not very serious. However, when aircraft is in takeoff, landing, and manoeuvring, the pumping source needs to supply more hydraulic oil to hydraulic actuators, the extra power losses and thermal loads will be produced. However, thermal loads in these stages are intermittent. For military aircraft, most of time is in high-Mach flight and combat, flight control surface is basically in action state, and the thermal load is larger than one of the civil aircraft. The analysis of power loss and thermal load of the main components of AHS and the method of establishing the system thermal dynamic model are discussed as follows:

For EDP and EMDP, the power losses mainly contain mechanical friction loss and leakage loss [1, 4]. In addition, EDP is affected by aerodynamic heating from sustained high-Mach flight in military aircraft [9]. For civil aircraft, mainly considering the thermal load inside EDP and EMDP, the thermal loads caused by the leakage in the valve and friction losses in the pipe are dissipated by the component surface, and the throttling losses in the valve is intermittent and the produced peak temperature can be endured and thermal load can be cooled during non-working period, so the temperature of the hydraulic oil is controlled through the cooling of case-returning oil. For military aircraft, the throttling losses in the valve is no longer intermittent, meanwhile the pipe length is shorter than one in civil aircraft, so the fuel heat exchanger needs to cool the case-drainage oil of primary pump and system returning oil in same time [4]. Therefore, heat-generation problem in military aircraft is obviously more serious than the civil aircraft.

The hydraulic reservoir and heat exchanger are generally located in airborne equipment bay whose temperatures are much lower than engine bay; meantime their thermal inertias are larger than other parts in hydraulic system [4], so thermal load of AHS is mainly absorbed in hydraulic oil tank and heat exchanger. Hydraulic oil flows in hydraulic pipe, and then brings about thermal load related to friction loss. However, considering the fact that the vast majority of hydraulic pipe is located inside the accessories equipment bay, and thermal load can be basically cooled by ambient cooling air. In many cases, the return pipe passes fuel oil tank, and it also cools part thermal load. The throttling loss of the servo valve especially for high-pressure hydraulic system will cause the large thermal load during the actuator operation. As about hydraulic actuator, because it connects with flight control surface and it will be exposed to outside cold air during working period, and its thermal load can be basically mitigated by outside cold air.
Primary pump: The formula of the power loss of the pump in the traditional text book is reasonable for no case returning oil pump. For the pump with case returning oil, we can draw power flow diagram shown in Fig. 4, and give the formula of the equivalent power loss of the pump as

\[ N_{pl} = N_{p0} - N_{plc} = (1 - \eta_m \eta_v)N_{in} - (1 - \eta_s)q_v(p_{out} - p_{in}) \]

(1)

where \( N_{in} \), \( N_{p0} \), \( N_{plc} \) are input shaft power, equivalent power loss, power loss without case returning oil, and hydraulic power of case returning oil port of the pump, respectively; \( p_{in}, p_{out}, q_v, \eta_m \) and \( \eta_s \) are case returning oil port pressure, output pressure, theoretical flowrate, mechanical efficiency and volumetric efficiency of the pump, respectively. The thermal load to applied to case returning oil pipe \( N_{plc} \) can be determined as

\[ N_{plc} = N_{in}(1 - \eta_s) \]

(2)

The calculating formula of power loss of the pump without case returning oil is

\[ N_{pl} = N_{p0} = (1 - \eta_m \eta_v)N_{in} \]

(3)

Compared (1) with (3), for the pump with case returning oil, the leakage power loss flows out from the case returning oil port, thus decreases the thermal load of the pump. It is important that the equivalent power loss of the pump with case returning oil pump is only defined from the viewpoint of thermal load generation, and the power losses of two kinds of pumps from energy conversion are same. Compared with EDP, EMDP easily adjusts the input shaft power and decreases the power loss from the source.

Hydraulic power mechanism: Hydraulic power mechanism, also named as actuating mechanism in aircraft, consists of the electro-hydraulic servo valve, position transducer, and hydraulic cylinder. The power loss of the actuating mechanism includes the power losses of servo valve and hydraulic cylinder, and its calculating formula can be written as

\[ N_{plh} = N_{plh0} + N_{plhc} = p_sq_{L}(1 - \eta_m \eta_{sv})/(\eta_m \eta_{sv}) + (\Delta p_{sv}q_{L} + p_{sv}q_{sl}) \]

(4)

where \( N_{plh0} \), \( N_{plhc} \), and \( N_{plh} \) are the power losses of actuating mechanism, servo valve, and hydraulic cylinder, respectively; \( p_{in}, p_{out}, \Delta p_{sv}, q_{L}, \) and \( q_{sl} \) are load pressure, supply pressure, valve port pressure, leakage flowrate, and zero position leakage flowrate of the servo valve \( q_{sv0} \), and its expression is

\[ q_{sv0} = q_{sl} + (q_{v0} - q_{sl})\exp\left(-\frac{i_v}{i_d}\right)^2 \]

(5)

where \( i_v \) and \( i_d \) are the coil electric current and threshold current of the servo valve. The threshold current is usually set as 20% rated current of the servo valve.

Filter and fluid resistance typed component: The power loss of fluid resistance-typed component is mainly produced by the orifice loss, and its relationship is as

\[ N_{plf} = \Delta p_{fs}q_{f} \]

(6)

difference, load flowrate, and leakage flowrate of the servo valve, respectively; \( \eta_m \) and \( \eta_s \) are mechanical and volumetric efficiency of hydraulic cylinder.

Fig. 5 is a measured leakage flowrate curve of the servo valve. As seen from Fig. 5, the shape of the curve is very close to the Gauss curve in Mathematics, so we can use Gauss function to approximate the leakage flowrate curve. The leakage flowrate of the servo valve T contains leakage flowrate of pre-hydraulic amplifier \( q_{sl} \) and zero position leakage flowrate of the servo valve \( q_{sv0} \), and its expression is

\[ q_{sl} + (q_{v0} - q_{sl})\exp\left(-\frac{i_v}{i_d}\right)^2 \]

where \( \Delta p_{sv} \) and \( q_{sv} \) are the valve-port pressure difference and the passed flowrate of the valve-typed component, and \( p_{sv} \) and \( q_{sv} \) satisfy the flowrate–pressure difference relationship of the valve. For hydraulic accessories such as filter, heat exchanger, and pipe connector, their power losses are also produced by local losses. The rated local loss when the rated flowrate passes the component can be looked up from the catalogue, the power loss when flowrate \( q_{sv} \) passes the component can be written as

\[ N_{pl} = \Delta p_{eh}q_{eh}/q_{eh}^2 \]

(7)

where \( \Delta p_{eh} \) and \( q_{eh} \) are rated local pressure loss, rated flowrate and passing flowrate of the accessory component.

Thermal dynamic model and solving method: There are two kinds of thermal dynamic model of aircraft hydraulic system, one is the lumped thermal dynamic model which takes the whole aircraft hydraulic system as the same temperature, and another is the state equation which takes the node temperatures of the hydraulic system as state variables based on heat nodes network. The former is suitable for the thermal analysis of the overall AHS, and the latter is fit for the temperature analysis of each component of AHS. Here, we study the first kind of thermal dynamic model. Based on analysis to the energy balance of AHS, the thermal dynamic model of hydraulic system is described as follows:

\[ (c_h\rho_hV_h + c_hk_hm_h)\frac{dT_h}{dt} = Q_L - Q_L\Delta t_k - K_hA_{ba}(T_h - T_{ah}) \]

(8)

where \( T_h \) is the average temperature of the overall hydraulic system, \( T_{ah} \) is the ambient temperature of airborne equipment bay, \( V_h \) is the hydraulic oil volume in whole hydraulic system (tank, pipe, pump, filter, and actuator), \( c_h \) and \( k_h \) are the specific heat of the hydraulic oil and the equivalent specific heat of the heated components.
respectively, \( k_{\text{ht}} \) is the heat transfer coefficient (usually setting as 0.3), \( K_{\text{fl}} \) is the thermal load coefficient of AHS, \( A_{\text{ht}} \) is the heat transfer area of fuel oil and hydraulic oil, and \( T_f \) is the temperature of the fuel oil in fuel tank, respectively.

In order to conduct the dynamic analysis on the temperature of AHS, a table on duration time and thermal load a flight mission profile should be firstly calculated which is shown in Table 1, next the state equations need to be solved by stages in a flight mission profile, then the relationship between temperature and time in a flight mission profile is obtained.

### 3 Overview to thermal management scheme and some considerations

Thermal management of AHS means to manage the heat sink and heat exchanger according to the thermal load and temperature of AHS, and make the temperature of AHS be in allowable range at lower cooling cost. This section will overview to thermal management and give some considerations.

#### 3.1 Overview to thermal management

In recent years, many efforts have been made towards thermal management schemes from heat dissipation and heat load reduction in flight mission profile. On heat dissipation, thermal load is usually dissipated through the hydraulic pipe, hydraulic oil tank and fuel heat exchanger. These hydraulic accessories are mostly located inside airborne equipment bay, and the main heat sinks are the cooling air in bay, fuel, and ram air. For civil aircraft, the heat can be collected in hydraulic oil tank \([1, 4]\), and then utilises cooling airflow inside airborne equipment bay or heat exchanger (shown in Fig. 6) inserted in reservoir to absorb the thermal load. Additionally, a part of hydraulic pipe passes through fuel tank (A320) or heat exchanger immerged in fuel tank (HXIFT, e.g. B737) can cool the thermal load. The thermal load to be absorbed by fuel based will decrease the cooling cost because the heat fuel is directly burned and heat fuel will make fuel sufficiently burned. Fig. 7 denotes the thermal management scheme of B737.

As for fighters, due to its sustained combat and high-Mach flight state, most of time its hydraulic actuators are in sustained action state, then it will face more severe heat-generation problem. Meantime, multi-fuel tank with small volume distributed in aircraft does not fit in HXIFT. Therefore, the heat exchanger is adopted two-fluid-forced convection heat exchanger (TFFCHX, in general, hydraulic oil/fuel oil), and is installed the returning oil pipe near hydraulic tank. The case drainage oil of the pump and system returning oil merges and then flows in the inlet of TFFCHX. As for its heat sink, earlier AHS adopted ram air, the current aircraft uses fuel oil as heat sink for saving cooling cost \([10]\). Therefore, TFFCHX, tank and pipe are main heat-dissipation components. In order to prevent fuel oil from cooking, the fuel oil temperature at TFFCHX outlet must be limited, which needs to control the returning fuel oil temperature through fuel-oil/ram-air heat exchanger \([5, 10]\). A combined heat exchanger is adopted in A380 hydraulic system. Fig. 8 is fuel oil thermal management system of large civil aircraft, fuel oil needs to absorb the thermal loads of lubrication oil and hydraulic systems, and meantime the ram air cools the returning fuel oil. F-22 thermal management system, shown in Fig. 9, it is the most successful thermal management system, and it utilises fuel as heat sink for the environment control system (ECS), hydraulic system and airframe gearbox lubrication system with the help of digital control \([11]\).

Li et al. \([12]\) established thermal model and then made analysis through simulation and experiment towards internal heat generation of EDP, thus the model effectiveness was verified. Additionally, with regard to very severe heat-generation problem, high-temperature resistant hydraulic oil and sealing materials have been adopted in AHS to prevent hydraulic oil from leakage and high-temperature failure.

Thermal insulation material also has been assembled around EDP due to the intense heat radiation from engine to piston pump. Many
Fig. 10 Layout EHA

Fig. 8 Fuel thermal management system of large civil aircraft

Fig. 9 Overall thermal management system of F-22

The flowrate of axial piston pump can be adjusted through displacement and rotating speed. For EDP, although its displacement can be adjusted by the load of flight mission, its rotating speed cannot get self-adjustment, and then it will inevitably lead to unnecessary power loss coming from uncontrollable rotating speed [7]. Therefore, the Air Force has tried a lot to utilise EMDP as pumping source in MEA. With the key advancements in high-power density servo motor, power electronics and digital control technologies, there has been a great deal of interests in the MEA concept. Electric motor drives are capable of converting electrical power to drive actuators, pumps and compressors at variable speed [15]. Electric motor-driven fuel pumps provide variable speed solutions to control the fuel flow rate which matches the actual demand [16]. EMDPs can provide variable speed to control the output flow rate of hydraulic pump through the order of flight control computer. Hydraulic and pneumatic actuation has been gradually replaced by PBW actuation called as distributed energy actuation. Compared with conventional hydraulic actuation, PBW does not need the centralised hydraulic source and hydraulic pipe over the airplane [17, 18]. Therefore, PBW actuator is characterised by small size, light weight, high-power density, maintainability, survivability and flexibility compared with hydraulic actuator.

There are four kinds of PBW actuation configurations called as EHAs, integrated actuator packages (IAPs), EMAs and electro hydraulic backup actuator (EBHA) [18, 19]. EHA, shown in Fig. 10, is defined as a self-contained electric actuation system that uses servo motor driving a reversible and fixed hydraulic pump to operate a hydraulic ram. IAP is defined as a self-contained electric actuation system that uses a constant speed motor driving a servo-controlled hydraulic piston pump to operate a hydraulic ram. EMA is defined as an electric actuation system that uses servo motor mechanically coupled to gearbox to operate aircraft load. EBHA is one cylinder, respectively, controlled by electro-hydraulic servo-valve or electric-servo motor-driven pump, but the latter only acts as backup function while hydraulic part failure. IAP still has distinct advantages over the conventional hydraulic actuation.

The A380 flight control actuation system adopts 2H/2E configuration which features two hydraulic systems and two electric systems. EHA and EBHA have been adopted to actuate local pressure state during other action periods. This thermal management scheme has been adopted in F/A-18E/F hydraulic system, its performance has improved a lot with comparison to former scheme [13, 14]. To further decrease the heat-generation problem, the US Air Force has developed intelligent pump which can produce continuously variable pressure and variable flow according to the flight state change through instructions of flight control computer, this scheme is only in stage of simulation and experiment prototype, not adopted by the aircraft in-service, but currently has shown favourable performance.

great efforts to improve heat-generation problem of pumping source have been made over the years. The earlier aircraft adopted gear pump with fixed displacement whose flow only can be adjusted by relief valve. Then its overflow loss easily leads to large heat-generation problem. Currently, fixed displacement pump has been replaced by piston pump with constant pressure variable displacement. Most of aircrafts have adopted fuel/hydraulic oil heat exchanger, hydraulic pipe and hydraulic oil tank to conduct thermal management of hydraulic system. However, in recent years it has brought about very severe heat-generation problem with the increasingly trend of high pressure and electro-hydraulic actuation which features two hydraulic systems and two electric power to drive actuators, pumps and compressors at variable speed [15]. Electric motor-driven fuel pumps provide variable speed solutions to control the fuel flow rate which matches the actual demand [16]. EMDPs can provide variable speed to control the output flow rate of hydraulic pump through the order of flight control computer. Hydraulic and pneumatic actuation has been gradually replaced by PBW actuation called as distributed energy actuation. Compared with conventional hydraulic actuation, PBW does not need the centralised hydraulic source and hydraulic pipe over the airplane [17, 18]. Therefore, PBW actuator is characterised by small size, light weight, high-power density, maintainability, survivability and flexibility compared with hydraulic actuator.

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flight control surface such as ailerons, spoilers and rudders [7, 21]. The B787 flight control actuation system adopts three hydraulic systems (left, centre, and right) and one electric system. In the hydraulic system, EMDP is no longer as back-up function than supplies hydraulic oil to centre channel hydraulic system, and its displacement is almost equal to one of EDP. In B787, some flight control surfaces are actuated by EMA. Moreover, B787 had firstly adopted electric braking and electric compressor. The use of electric actuation in 787 obviously decreases idle power loss and oil leakage, and then simplifies AMAD [7]. EMDP is also used to accurately regulate fuel of the engine in MEA fuel system.

F-35 fighter completely eliminates the central hydraulic power source and it utilises PBW with 270 V DC electric power transmission and distribution of built-in starter/generator, and terminal actuation with EHA and EMA. Its layout is shown in Fig. 11. Meantime, this kind of aircraft also adopts thermal and energy management module (T/EMM) which combines the functions of auxiliary power unit, emergency power unit, ECS and starter/generator into an integrated package, thereby further simplifying AMAD and improving aircraft penalty. Hydraulic system driven by T/EMM only acts as back-up function [22, 23].

Towards flight control actuation, EHA is the first choice due to its advantages such as oil self-lubrication, easily locking and by-passing, and high-power density compared with EMA [24, 25]. However, no matter EHA or EMA, local heat-generation problem is very severe when the ambient temperature is high. It needs to take great efforts to develop thermal management facilities to cope with this problem [26]. Kai Li and Zhong Lv firstly analysed thermal mechanism of piston pump and EHA, then established their thermal model to calculate the temperature of key nodes. The result showed that heat generation of EHA is obviously more critical than piston pump [27]. Aimed at local heat generation problem of EHA, Won-Zon Chen and Tsugin Lin established 24-node thermal model and then conducted numerical simulation to calculate its components such as motors, pumps and actuator cylinders, thereby investigating worse-case operation and evaluating packaging concept [28].

In view of the thermal load of EHA is intermittent, and its heat generation is severe only in high ambient temperature, forced electric turbine cooling and heat-accumulated through phase change materials cooling are available thermal management solution scheme.

3.2 Some considerations on thermal management

Thermal management of AHS greatly depends on the effective utilisation of heat sink and heat exchanger. Through the above analysis and discussion, some considerations on thermal management are as follows:

(1) To set up the necessary switch valve and bypass overload valve for heat exchanger in thermal management system provides the basic management conditions and meantime prevents from heat exchanger blockage.

(2) To use variable pressure EDP and EMDP provides the hydraulic power according to the needs and decreases the power loss from the earliest source.

(3) The thermal management scheme without returning fuel is firstly taken, and the second is one of with the returning fuel oil and fuel/ram air heat exchanger.

(4) For EHA with the intermittent thermal load, its heat generation is severe only in high ambient temperature, and forced electric turbine cooling and heat-accumulated through phase change materials cooling are available thermal management solution scheme.

4 Conclusions

This paper surveyed the present status of thermal analysis and thermal management of the AHS, and proposed several considerations. The main conclusions are as follows:

(1) The central hydraulic pump supplies adopt EDP and EMDP, the present pump is with constant pressure and variable displacement, dual-stage pressure pump and variable pressure pump can effectively decrease the power loss while hydraulic being meddle and low load case.

(2) The thermal load comes from the power losses of AHS, and the thermal load of the hydraulic system of civil aircraft and fighter is different characteristics.

(3) Compared with EDP, EMDP can easily regulate the hydraulic power output of the pump, which may decrease the idle power loss of hydraulic system. Therefore, EDP has been partially replaced by EMDP in MEA, especially in B787.

(4) Part more electric scheme, B787 has adopted electric braking and part flight control realised by EMA and EHA, A380 used EHA and EBHA for some local flight control surface, and even in F-35, the central hydraulic system has been completely replaced by PBW actuation system with EHA and EMA.

(5) For military MEA, EHA and EMA will face relatively serious local heat management problem while high Mach-number flight, this needs to be carefully addressed.

The future works are to apply the established the calculation method of thermal load, the established thermal dynamic model and the proposed thermal management shame to the actual aircraft hydraulic system and to evaluate their availability.

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