

Next Generation Power and Thermal Management System

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ABSTRACT

The power and thermal management system (PTMS) developed by Honeywell for aircraft is an integral approach combining the functions of the auxiliary power unit (APU), emergency power unit (EPU), environmental control system (ECS), and thermal management system (TMS). The next generation PTMS discussed in this paper incorporates the new more electric architecture (MEA) and energy efficient aircraft (EEA) initiatives. Advanced system architectures with increased functionality and further integration capabilities with other systems are included. Special emphasis is given to improvements resulting from interactions with the main engine, main electric power generation, and flight actuation. The major drivers for advancement are highlighted, as well as the potential use of new technologies for turbomachinery, heat exchangers, power electronics, and electric machines. More advanced control and protection algorithms are considered.

INTRODUCTION

Honeywell is a major system and component supplier and a system integrator for commercial and military aircraft and space vehicles, and has a broad portfolio of mechanical and electrical products. With these unique capabilities, Honeywell has been able to combine the functions of previously federated subsystems into an integrated system to reduce weight, volume, and cost while improving reliability. Honeywell has advanced system integration by combining the functions of the APU, EPU, ECS, and TMS. This innovative PTMS is revolutionary because the integrated system approach allows the same turbomachinery to be used for producing power and cooling. For aircraft using federated subsystems, the APU is used only on the ground and becomes a weight penalty once airborne. The EPU is used only when the main power generation system fails. Therefore, the aircraft is penalized by the weight of the idle EPU during normal operation. In the PTMS, since the same turbomachinery is used for producing power for the APU and EPU, and for producing cooling for the ECS and supporting TMS functions, the aircraft does not incur penalties. This

benefit reduces weight, volume, and cost while increasing the reliability of the aircraft.

The MEA initiative imposes a new environment where the main engine operates more efficiently and electrical actuation replaces the heavy and unreliable hydraulic and pneumatic components. The introduction of the PTMS is a big step toward MEA. The next generation PTMS is expected to progress even further in this direction by more integration with the main engine, main power generation, flight control actuation, and other systems. Improved power extraction, electrical utilization, and thermal management will be achieved. The PTMS will be an integral part of the overall airplane energy management, resulting in improved vehicle performance. To achieve this objective, the next generation PTMS will implement new architectures with new modes of operation and use more advanced subsystems and components with highly improved efficiencies.

BACKGROUND OVERVIEW

The PTMS is based on an advanced system integration concept developed and tested by Honeywell. The PTMS reconfigures itself to operate in four major modes: (1) self-start mode (SSM), (2) main engine start (MES) mode, (3) cooling mode (CM), and (4) emergency power mode (EPM). In the SSM, the PTMS uses electrical power from the aircraft battery via the starter/generator (S/G) to accelerate the turbomachinery. The compressor operates in an open loop mode. The compressor inlet is opened and the compressor draws in ambient air. The compressor outlet air is sent to the combustor. Fuel is injected into the compressed air through the combustor to significantly increase the gas temperature. The combusted gas is sent to the power turbine, where it is expanded. The power absorbed through the expansion in the power turbine is used to drive the compressor and produce the electrical power. Once the turbomachinery spins up to an initial speed, the starter/generator no longer needs electrical power from the aircraft battery, and the PTMS is transitioned to a self-sustaining operation. Then PTMS is able to produce power through the combustion of fuel only. The same starter/generator that provides electrical power output to start the main engine is used for SSM To spin up until light-off of the combustor.



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Once the PTMS has gone through SSM, it is ready to perform a MES or ground check out (Figure 1). In MES, the PTMS produces power from the combustion of fuel to provide electrical power output through the starter/generator. The electrical power is fed into the main engine starter/generator to start the main engine.

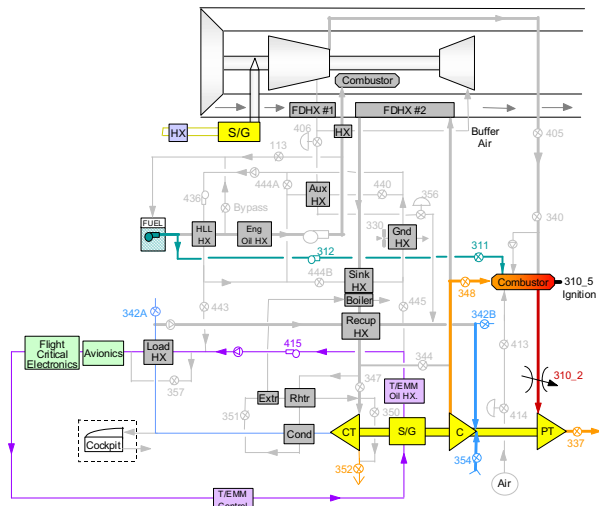


Figure 1. PTMS Main Engine Start Mode (Traditionally Provided Separately by an APU)

After the main engine has been started, the PTMS transitions to the cooling mode (Figure 2). In this mode, the combustor is no longer used and the PTMS is powered by the high stage bleed air from the aircraft engine. The compressor operates in a semi-closed loop configuration. The compressor inlet is closed from ambient air and compressed air is cooled by the fan duct heat exchanger #2. It is further cooled by expansion through the cooling turbine. Part of the cooled air from

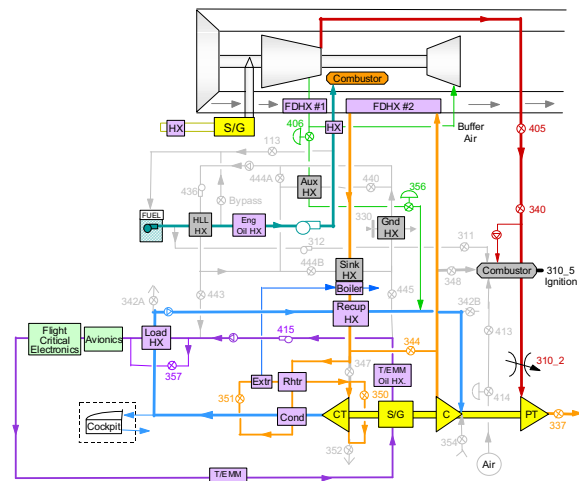


Figure 2, PTMS Cooling Mode (Usually Provided Separately by ECS and TMS)

the turbine outlet is sent to the cockpit to supply pressurization and air conditioning. The remaining cooled air from the turbine outlet is used to pick up heat from the avionics, flight critical electronics, and other

liquid cooled heat loads. This hot air is recirculated to the compressor inlet. The other part of the compressor inlet air is from high stage bleed air after it has been cooled by fan duct heat exchanger #1.

Should an in-flight main engine failure occur, the PTMS is reconfigured into the emergency power mode (Figure 3). In this mode, the compressor transitions to an open loop mode, similar to the main engine start mode. The compressor inlet opens and the compressor draws in ambient air, compresses the air, and sends it to the combustor. The compressed air is combusted with fuel. The combusted gas is sent to the power turbine and expanded in the power turbine to produce power to operate the PTMS and produce electrical power. The electrical power output can be continuous to supply the flight critical electrical equipment or transient to provide higher peak power levels used for main engine re-start.

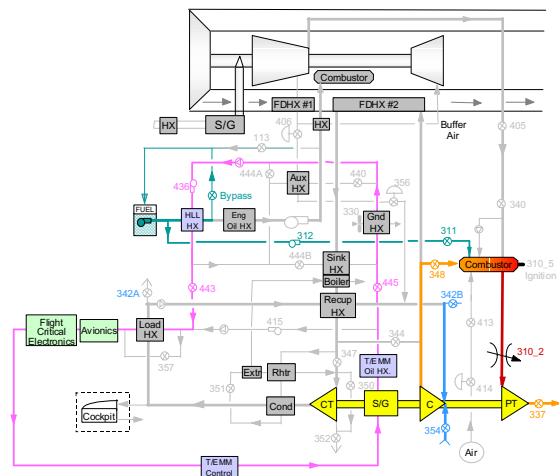


Figure 3. PTMS Emergency Power Mode–Air Breathing (Usually Provided by Emergency Power System)

ADVANCED AIR AND THERMAL MANAGEMENT SYSTEM ARCHITECTURES

The next generation PTMS can benefit from advancements in energy efficiency, adaptability, more integration, and component advancements.

ENERGY EFFICIENT – The PTMS is powered by high stage bleed air from the aircraft main engine. Using high stage bleed air causes engine fuel inefficiencies. Using lower stage bleed air, electrical power, or a combination of the two to operate the PTMS will result in a reduction in fuel penalty. This translates into more capability, lower weight, and less fuel usage. The recent evolution in MEAs has created more electrical power available for electrically powered systems. Powering the PTMS electrically is aligned with the MEA evolution.

ADAPTABILITY – Many benefits result from systems that can adapt to shed heat loads to varying available heat sinks. Heat sinks available on a modern aircraft include fan air, and ram air. Not accounting for transients, the

amount of heat sink available in fuel is directly proportional to the fuel flow combusted in the main engine. For non high thrust settings where the engine does not burn the most fuel, enough heat sink is available in the fuel. The amount of heat sink available in fan flow is much higher than that for fuel, due to the large amount of fan air going through the outside bypass of the engine. The down side of using fan air is, the temperature is higher than the fuel and ram air. This means that the thermal management system has to take in more energy to lift the heat transfer medium to be able to dump heat to the higher temperature fan air. For the thermal management system, ram air is the most energy efficient heat sink. However, ram air causes drag on the vehicle, and additional openings and exits must be added. Different sources of heat sinks are a better choice for different operating conditions. By having a system that can adapt to using the best available heat sink, the system can be more energy efficient.

There are benefits for a system that can adapt to using different energy sources as well. The PTMS can be powered pneumatically or electrically. Usually powering the system electrically is more energy efficient. However, there may be modes where electrical power is needed by other sub-systems. In such a scenario, temporarily powering the PTMS pneumatically is needed. Adapting to different energy sources adds flexibility to the PTMS and provides additional capability to the air vehicle.

MORE INTEGRATION – Due to the versatility of the PTMS, more functions can be integrated into the PTMS. Some possible functions include peak and regenerative power management.

ADVANCED TURBOMACHINERY

High temperature foil bearing – Honeywell invented the foil bearing, which reduced the weight and volume of turbomachinery through the deletion of the lubrication system and equipment. For application to the PTMS, the foil bearings must be adapted for the high-temperature environment.

High efficiency compressor – By increasing the efficiency of the compressor, the turbomachinery weight and size can be reduced.

High temperature turbine – By increasing the turbine inlet temperature, the turbomachinery weight and size also can be reduced. Alternatively, for the same weight and size turbomachinery, an increase in turbine inlet temperature will allow for high electrical power output. The challenge is that the combustor, turbine wheel, and housing must all be able to withstand the higher temperatures. One approach is to change the turbine wheel material, which results in lower weight and less system penalty, but requires more investment and time to develop. Another approach is to use colder air to cool the turbine wheels, which requires resolution of some engineering problems and is less risky. However, the weight and packaging gains are less than those

achieved by changing to a higher temperature capable turbine wheel material.

Variable geometry turbine – A variable geometry turbine allows the power turbine and cooling turbine to have high efficiency through wider operating conditions. Traditional systems that do not use variable geometry turbines are designed to achieve the highest efficiency point for the design case. In off-design conditions, the efficiency of the turbine decreases. By using a variable geometry turbine, the amount of bleed air to power the system can be decreased due to the higher efficiency.

ADVANCED HEAT EXCHANGER – Heat exchangers substantially add to the total environmental control and thermal management system weight and volume. Advanced heat transfer surface technologies lead to lower weight and smaller volume heat exchangers, which has a significant impact on the total system weight and volume. Some of the advanced heat transfer surface technologies include micro channel and foam heat exchangers. These technologies are being developed to increase the heat transfer surface area per unit volume so that more heat transfer can be achieved for the same volume. A microchannel heat exchanger stacks more heat transfer fins than traditional brazed plate-fin heat exchangers. The technology challenge is to develop a manufacturing process to produce microchannel heat exchangers that avoids fouling with contaminants..

ADVANCED ARCHITECTURE – A potential advanced PTMS architecture that incorporates some of the desired features summarized above is shown in Figure 4 (see Reference 2). This advanced PTMS architecture uses the indirect regenerative air cycle for integrated power and cooling machines. The system is bleed powered. Depending on the engine setting, high stage bleed air, intermediate stage bleed air, or fan air could be used to power the system. Usually at ground idle, the intermediate stage bleed air and fan air pressures are not high enough. Therefore, high stage bleed air must be

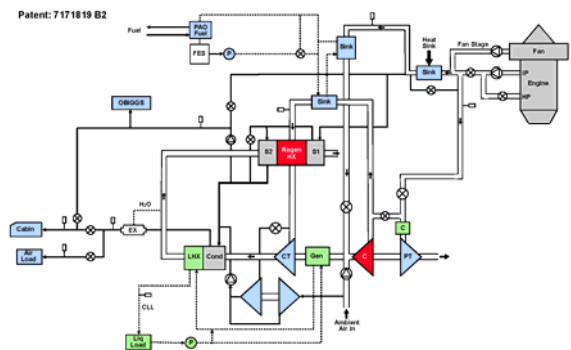


Figure 4. Indirect Regenerative Air Cycle for Integrated Power and Cooling Machines

used. When the aircraft is in flight, the intermediate stage bleed air and fan air pressures are higher than at

ground idle and the system can be powered by intermediate stage bleed air and sometimes even by fan air. By reducing the use of high stage bleed air, which penalizes the engine specific fuel consumption (SFC) and aircraft fuel consumption, aircraft energy and fuel savings are achieved. This system inherently extracts more energy from the available bleed air. In a traditional PTMS system, most of the power needed to drive the PTMS is provided by the power turbine. The power expanded through the cooling turbine is limited by the turbine outlet pressure, which is dictated by the cockpit pressure. In the traditional PTMS, the cooling turbine outlet air is used to pressurize and cool the cockpit. In this advanced PTMS architecture, the cockpit pressurization and cooling air are not provided by the cooling turbine. The cooling turbine outlet is vented into the aircraft ambient, which has a low pressure compared to the cockpit pressure, and can be used as bay cooling. This allows a higher pressure ratio across the cooling turbine, which allows more power to be extracted from the source bleed air. In the advanced system, less power to drive the system is provided by the power turbine and more power contribution is from the cooling turbine. The higher pressure drop across the cooling turbine also results in a greater temperature drop across the cooling turbine. To perform the same cooling with a lower supply temperature, less bleed air flow is needed.

MAJOR REQUIREMENTS AND FUNCTIONS OF AN EPGS

An electric power generation system (EPGS) suitable for the PTMS needs to satisfy a complex set of requirements, described in greater detail in Reference 3. Typical functional and safety requirements are overviewed below.

Electrical generation is the main function of such a system, providing conversion of the mechanical shaft power supplied by the PTMS to conditioned electrical power delivered to the distribution bus. Generation is typically defined as continuous power at 100 percent load. Increasing the load to 150 percent for a limited time may be required. The percentage of increase and time required for overloading varies from application to application.

Steady-state regulation is a function that maintains the generated output voltage constant within certain limits when the electrical loads and other conditions are gradually changed.

Transient regulation is a function that maintains the output voltage constant within certain limits when the loads and other conditions are changed rapidly. Transient limits are wider than steady-state limits. Typical regulation requirements are specified in MIL-STD-704E.

Electromagnetic interference (EMI) conducted and radiated emissions are important requirements for an EPGS to provide proper operation of the installed electronics. At the same time, the electronic equipment, including the EPGS, must not be susceptible to the specified radiated emissions. Typical EMI requirements are specified in MIL-STD-461.

The dc bus short-circuit protection function is required when an external short circuit fault occurs at the dc distribution bus. The protection system uses it for clearing the fault. This current is slightly higher than the maximum operating current and is required for several seconds.

The feeder short-circuit protection function is required to prevent excessive current flow in the electric machine and the interface to the electric machine and power electronics. The purpose is to reduce damage.

The power electronics short-circuit protection function is required to prevent excessive current flow in the power electronics unit.

Overvoltage protection is required to prevent excessive voltage across a power distribution bus. Overvoltage protection prevents damage to the electronics connected to the distribution bus.

Overload protection should occur when the available mechanical power is less than the electrical power demanded at the output of the EPGS.

The EPGS provides the motoring SSM until self-sustaining operation of the PTMS engine is achieved. During the MES, the EPGS delivers very high power with highly demanding transient currents. After MES, the system transitions to a CM, where very small amounts of power are delivered for aircraft avionics and internal supply. During CM operation the EPGS is waiting to perform emergency power in case some of the main generators fail. Most of the time during normal airplane operation, the EPGS is underutilized.

The power topology of an EPGS using a high-reactance, permanent-magnet machine (HRPMM) is presented in Figure 5. The topology contains a three-phase bridge, a dc link capacitor bank, an EMI filter for the dc bus, and a contactor. Current and voltage measurement devices required for control and protection purposes are included. This simple topology satisfies all functional requirements discussed in this paper. The topology has bidirectional power flow capability. The synchronous rotation of the electric machine is performed for service motoring and SSM. Power generation is achieved by applying the appropriate voltage to the machine terminals to extract the required power and at the same time dc bus voltage is regulated to the desired value.

A unique feature of this topology is to provide short-circuit current at the dc bus during generation to clear the fault. If the dc bus is overloaded, the control system reduces the output voltage linearly to prevent components from being damaged. Below certain voltage levels, control of the three-phase bridge is not possible. Here, a pure diode rectification is used. The reactance of the machine is selected such that the short circuit of the machine satisfies the requirements of the dc bus short circuit current. The typical ratio between these two currents is 1.35. The ratio may vary depending on component selection for the bridge and the EMI filter.

When a short circuit occurs within the power electronics, the machine, or the interface between the power electronics and the machine, control of the generation process will be instantly discontinued. The failure current will be limited by the HRPMM and will be comparable to the maximum operating current. Therefore, mechanical failure that could cause degradation of the remaining PTMS functions is not expected.

MAJOR DRIVERS FOR ADVANCEMENT OF EPGS AS A PART OF PTMS

MORE ELECTRIC ARCHITECTURE TRENDS – The EPGS has a significant role in the modern aerospace industry. This is particularly true in the area of MEA for aircraft and spacecraft. The commercial aircraft business is moving toward electrical actuation. A typical example is the Boeing 787 platform. The next-generation Boeing

airplane and the Airbus airplane will most likely use MEA. Some aircraft already utilize MEA for primary and secondary flight control, among other functions. Also, an increase in the installed radar equipment and modern weapons requires much higher power. Ground vehicles have migrated toward hybrid electric technology, where the main propulsion is performed by electric drives. Reference 4 describes such a system. Future space vehicles will require EPGSs for thrust vector and flight control actuation discussed in Reference 5. Compared to the existing Space Shuttle power systems, these systems must be more robust, and they will offer greatly reduced operating costs and greater safety. Those aspects are well covered in Reference 6. These new aerospace trends, however, have significantly increased power generation needs. This has led to increased operating voltages to reduce system losses, weight, and volume. Overall system performance improvement and power density increases are necessary for the new-generation hardware to satisfy MEA. A new set of power quality and EMI requirements has been created to satisfy both quality and performance. Efforts to decrease the cost of EPGSs will make the new platforms more affordable. As a part of the PTMS, the EPGSs contributed substantially to the advancement of MEA technology. The first production implementation of on-shaft generation at this high power level and HRPMM implementation pushed the envelope even further. The next generation PTMS will definitely follow the overall tendencies resulting from MEA and contribute to further advancement.

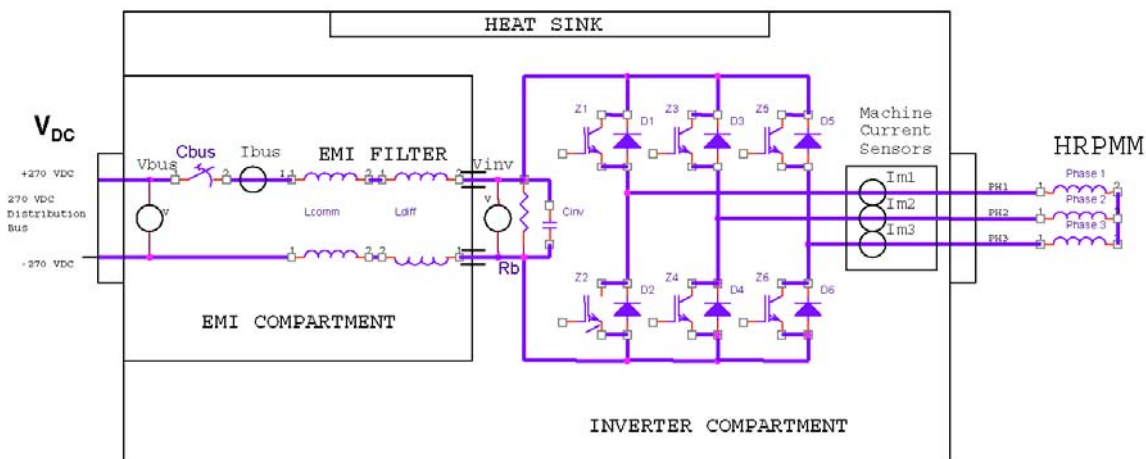


Figure 5. Power Topology of HRPMM Based EPGS for PTMS