APPARATUS AND METHOD OF DISABLING A WASTE HEAT RECOVERY APPARATUS WORKING FLUID FLOW

ABSTRACT
An apparatus and method for operating Waste Heat Recovery system based on a Rankine cycle and including a vaporizer/boiler heated by an internal combustion engine exhaust waste heat, an expander, a condenser, and a pump for circulating a working fluid through the circuit, includes a shutoff valve placed at the inlet side of the pump and controlled in the event an emergency shutdown is needed to stop working fluid circulation by closing and causing the pump to cavitate.
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FIELD OF THE INVENTION

[0001] The invention is directed to a Waste Heat Recovery system based on a Rankine cycle, including a working fluid circuit having a vaporizer/boiler heated by waste heat of an internal combustion engine, an expander, a condenser, and a pump for circulating a working fluid through the circuit. More particularly, the invention is directed to a shutoff valve placed at the inlet side of the pump and controlled in the event a shutdown of working fluid circulation is needed.

BACKGROUND AND SUMMARY

[0002] In waste heat recovery (WHR) systems associated with internal combustion engines, it is convenient to mechanically connect the working fluid pump to a rotating component, such as the expansion machine or the internal combustion engine, to be driven by that component. In certain circumstances it is necessary to quickly stop the working fluid flow, for example because of a WHR component malfunction. Quickly stopping a mechanically driven pump may be difficult or impossible because of difficulty stopping the component driving the pump, which, as mentioned, may be the waste heat apparatus expander or the internal combustion engine. A malfunction may occur as a valve actuator failure or a line transferring fluid failing to contain fluid. Other circumstances may include a boiler (or evaporator) rupture, which could introduce flammable fluid into the engine, causing engine runaway. External failures, for example, a collision of the vehicle, could cause risk to operator and environment.

[0003] Possible solutions include using a separately controlled electronic pump or a shutoff valve downstream of the pump; however, neither of these solutions will mitigate risk in the event of uncontrollable pump operation, actuator failure, or line failure between pump and actuator.

[0004] According to the invention, an apparatus and method for controlling working fluid flow in a waste heat recovery apparatus includes a fluid shutoff valve positioned upstream of a working fluid pump to stop fluid flow to the pump, causing the pump to cavitate, when fluid flow is not desired.

[0005] According to another aspect of the invention, the shutoff valve is operationally connected to a controller, which may be an electronic control unit as is known in vehicles, which is itself connected to receive signals relating to the condition of components of the waste heat recovery system, and responsive thereto, control the fluid flow to the pump.

BRIEF DESCRIPTION OF THE DRAWING

[0006] The invention will be better understood by reference to the following detailed description in conjunction with the appended drawing, in which:

[0007] The sole FIGURE is a schematic of a waste heat recovery apparatus in accordance with the invention.

DETAILED DESCRIPTION

[0008] The FIGURE shows a schematic view of a waste heat recovery apparatus 10 for a vehicle having an internal combustion engine in accordance with the invention. The illustrated example of a waste heat recovery apparatus is one based on the Rankine cycle, and includes a working fluid circuit 12 to circulate working fluid to the apparatus components, including a boiler 20, an expander machine 22, a condenser 24, an accumulator or collection tank 26 and a pump 28.

[0009] The boiler 20 is arranged in heat transferring contact (heat transfer being indicated by the arrow Q) with a source of engine waste heat 14. The heat source 14 may be any heat generating or handling system associated with a vehicle having an internal combustion engine, including the engine exhaust, engine coolant system, the exhaust gas recirculation (EGR) cooler charge air cooler, engine oil cooler, or some combination of these. The boiler 20 heats the working fluid, which then flows to the expander 22 where work energy is extracted from the heated fluid. The work energy may be used, for example, to drive a generator, may be added to the engine drive shaft, or used to drive the pump 28.

[0010] The exemplary waste heat recovery apparatus 10 includes a bypass line 30 to guide working fluid to avoid the expander machine 22. The bypass line 30 is controlled by a bypass valve 32 to direct working fluid to the expander machine 22, to the bypass line 30, or to divide the working fluid for proportional flow through both the expander machine and bypass line as required by the system needs. Other bypass lines may be included, for example, a line bypassing the boiler.

[0011] The waste heat recovery apparatus 10 may include other valves and valve actuators to manage the flow rate, pressure and distribution of working fluid to the various system components.

[0012] The condenser 24 receives the expanded working fluid, which is cooled, condensed, and collected in the accumulator or tank 26. The pump 28 pumps the working fluid from the accumulator 26 to the boiler 20 where the cycle of heating and expanding repeats. As mentioned, the pump 28 may be driven by the expander machine 22 by connecting an input shaft 29 of the pump to an output shaft 23 of the expander machine. Alternatively, the input shaft 29 of the pump 28 may be connected to the drive shaft of the engine (not illustrated).

[0013] A shutoff valve 40 is disposed in the fluid flow circuit between the accumulator 26 and the pump 28, that is, on the inlet side of the pump. The shutoff valve 40 is operated to control flow of the working fluid to the pump 28. Under certain circumstances it is necessary to quickly shut off fluid flow in the fluid circuit 10. By closing the shutoff valve 40 at the pump inlet, no working fluid flows to the pump 28, which causes the pump to cavitate and effectively stops the fluid flow at the outlet side of the pump.

[0014] A controller 44, which may be the electronic control unit (ECU) for operating the waste heat recovery system or another controller on the vehicle such as the engine ECU, is connected to control the operation of the shutoff valve 40. The controller 44 is also connected to receive signals from the various components of the waste heat recovery system 10, the vehicle, and the internal combustion engine. The controller 44 may be connected on a common data bus with the other components, or may be directly connected to the components, as is convenient. In addition or in the alternative, the controller 44 may be connected to receive signals from an on-board diagnostics system that monitors the function of vehicle components, as is known in the art. The signals provided by the components and/or the diagnostics system convey information to indicate a condition of components of the waste heat recovery apparatus, the engine, or other vehicle components.
Signals indicating certain conditions are identified by the controller as trigger conditions for the shutdown of the waste heat recovery system 10. The controller 44 may include a memory storing trigger conditions and be configured to compare received signals to the trigger conditions to identify signals indicating the valve is to be shut off. The controller 44 is thus programmed to receive the signals and generate a control signal for the valve 40 responsive to the signals.

[0015] A trigger condition may be indicated when the vehicle is stopped with the engine running for inspection or service to avoid exposing an operator, inspector, service technician, or others to high pressure fluids during engine service. The trigger condition may be a signal that the engine is running along with a signal that the parking brake is engaged.

[0016] Another possible trigger condition is during engine braking, the waste heat recovery system being disabled during power absorption mode to avoid decreasing engine braking effectiveness. The trigger condition may be a signal that engine braking is activated.

[0017] A trigger condition may be indicated for a malfunction of a vehicle system, the engine, or the waste heat recovery system. For example, a leak or rupture in the boiler 20 could allow working fluid (which may be a flammable fluid) to flow into contact with the engine exhaust. A trigger condition here may be indicated by a pressure loss in the boiler.

[0018] Another trigger condition may be indicated by an actuator malfunction, for example, a malfunction of the bypass valve 32 or another of the valve actuators managing working fluid flow.

[0019] Other conditions that could trigger shutoff relate to the working fluid flow conditions. An abnormal or unexpected pressure or temperature signal may be recognized as a trigger condition. Pressure and temperature may be monitored in all fluid circuit legs, that is, the conduits between each of the pump, boiler, expander, condenser, and accumulator, by providing appropriate pressure and temperature sensors. A sudden pressure drop in one or more circuit legs (as compared to expected pressure), indicates a possible internal or external fluid leak. In the event of a pressure signal trigger, the shutoff valve 40 and other flow valves are closed. An abnormal temperature signal could indicate a malfunction of a system component, such as the boiler (abnormally low temperature signal) or the condenser (abnormally high temperature signal).

[0020] Another trigger condition is a malfunction of the internal combustion engine, which is described here as an example of an emergency shutdown situation. One type of engine malfunction that can affect the waste heat recovery system is a so-called "runaway" engine, indicated by an engine speed that exceeds an expected value for the current operating conditions. A runaway engine event may occur during downhill operation or may be caused by a fuel, coolant, oil, or working fluid leak into the intake manifold or power cylinder unit. To mitigate risk of component failure due to continuing runaway conditions, a signal is sent to the Rankine control system to stop all working fluid flow and enter a "safe" mode. The first action is to close the shutoff valve 40 at the accumulator 26 outlet/pump 28 inlet. This disables any further working fluid from circulating in the system, and is done in case the runaway event is caused by working fluid leaking into an engine cylinder and combustive. Working fluid may leak into an engine cylinder by failure of an EGR cooler connected to a heat exchanger or boiler of the waste heat recovery apparatus. For example, a crack, burst, external object damage or the EGR cooler in which containment of working fluid is compromised may allow working fluid to enter the EGR gas stream. Following closing of the shutoff valve 40, all other control parameters are sent to a predefined safe condition. Fluid flow to the boiler 20 is stopped and sent to bypass loops. Valves admitting fluid to the expansion machine are closed and the valve 32 is controlled so that working fluid bypasses the expansion machine and is directed to the condenser and tank.

[0021] All conditions are monitored until it is determined the engine and transmission are operating properly. Conditions in the system may be monitored using diagnostic methods of system and components, for example, the aforementioned on-board diagnostic system that monitors the engine response during working fluid shut-off. If it is determined to be possible to circulate the working fluid again, for example, signals indicating the fluid circuit under normal pressure, normal operation of the waste heat recovery system will resume. If, on the other hand, it is determined the runaway engine condition was due to working fluid entering the combustion chamber, a fault code is broadcast for the operator to service and repair the system. For example, after the valve shut-off, if engine function returns to normal, it can be assumed the runaway engine condition and a working fluid circuit abnormal condition are related. Also, a diagnostic system could monitor on engine start-up the ability of the waste heat recovery system to maintain and hold pressure, where, the ability to retain positive pressure indicates no leak being present. Multiple diagnostic methods could arrive at the same conclusion.

[0022] Other trigger conditions include Rankine system instability (inability of the system to respond to control system pressures, temperatures and flows), and inability of the system to control working fluid flow/pressure/temperature due to failed actuators or control algorithm error (the sensed temperature or pressure exceeds the allowable target for working fluid, or sensor failure causing faults, etc.).

[0023] The invention has been described in terms of an illustrative embodiment and components, but the scope of the invention is defined by the appended claims.

What is claimed is:

1. A method of operating a waste heat recovery apparatus associated with an internal combustion engine of a vehicle, the apparatus including a boiler, an expander, a condenser, and a pump connected on a circuit circulating a working fluid, comprising the steps of:

monitoring a status of selected components of a vehicle having an engine and a waste heat recovery apparatus;

detecting a trigger condition of at least one of the engine and the waste heat recovery apparatus for shutting off a working fluid flow; and,

closing a valve up of a pump inlet to stop working fluid flow to the pump.

2. The method of claim 1, comprising monitoring the status of at least one of a waste heat boiler, an expander, a condenser, an accumulator, and a working fluid circuit.

3. The method of claim 1, wherein the trigger condition is a signal indicating a pressure of the working fluid below a low pressure threshold.

4. The method of claim 1, wherein the trigger condition is fault code for a valve actuator of the working fluid circuit.

5. The method of claim 1, wherein the trigger condition is a signal indicating a collision involving the vehicle.
6. The method of claim 1, wherein the trigger condition is a signal indicating is a malfunction of the internal combustion engine.

7. A waste heat recovery apparatus for a vehicle having an internal combustion engine, comprising:
   a waste heat boiler an expander, a condenser, and a fluid pump arranged on the fluid circuit;
   a shutoff valve disposed on the fluid circuit between the condenser and fluid pump; and,
   a controller connected to the shutoff valve and configured to shutoff fluid flow in the fluid circuit upon receipt of a signal indicating an abnormal condition in a component arranged on the fluid circuit.

8. The waste heat recovery apparatus of claim 7, wherein the controller is connected to receive signals from vehicle systems, and wherein the controller is configured to shut off fluid flow in the fluid circuit upon receipt of a signal indicating a malfunction of the internal combustion engine.

9. A vehicle having a waste heat recovery apparatus, comprising:
   an internal combustion engine;
   a waste heat recovery apparatus including a waste heat boiler, an expander, a condenser, and a fluid pump arranged on a fluid circuit, the waste heat boiler being connected to receive waste heat from the engine to heat a working fluid;
   a shutoff valve disposed on the fluid circuit between the condenser and the fluid pump; and,
   a controller connected to the shutoff valve and connected to receive signals indicating a condition of the internal combustion engine and waste heat recovery apparatus, the controller including a memory storing trigger conditions for closing the shutoff valve and configured to compare a signal received to the trigger conditions and to close the shutoff valve upon receipt of a signal indicating a trigger condition.

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