forwards with more power. There is no limit in the Regulations to the excess power generated in the MGU-H if it can be fed to the MGU-K for increased power and speed.

[0009] The harnessing of wasted heat energy using the known technologies has provided significant performance benefits for lower fuel consumption and emissions. However, the amount of converted useful energy is still only a small proportion of the total energy that is wasted. Furthermore, the current technologies used in the 2014 Formula 1 season have had the undesirable consequence of diminishing the noise level of the V6 engine, already reduced from the distinctive noise level of the V8 engines used in previous seasons, a factor that has proven to be controversial in spectator enjoyment of the sport.

Object of Invention

[0010] Embodiments of the present invention seek to improve upon the prior art or to provide a useful alternative thereto.

Summary of Invention

[0011] There is disclosed herein an internal combustion engine heat energy recovery system, comprising:

a first heat exchanger arranged in heat communication, via fluid communication, with at least one heat energy source of an internal combustion engine and with a working fluid of the system for the transfer of heat energy from the heat energy source to the working fluid of the system;

a turbine arranged in fluid communication with the working fluid heated in the first heat exchanger for the expansion of the working fluid to produce shaft power;

a second heat exchanger arranged in heat communication, via fluid communication, with the expanded working fluid to remove waste heat therefrom and transfer it to an external source such as the atmosphere; and a first compressor arranged in fluid communication with the working fluid exiting the second heat exchanger for increasing the pressure of the cooled working fluid prior to its entry into the first heat exchanger, wherein the working fluid of the system is a supercritical fluid, at least prior to its entry into the turbine; and a recuperator arranged in heat communication, via fluid communication, with the working fluid upon its exit from the internal combustion engine for the transfer of heat energy to the working fluid prior to its entry into the first heat exchanger.

[0012] There is disclosed herein an internal combustion engine heat energy recovery system, comprising:

a first heat exchanger arranged in heat communication, via fluid communication, with a first heat energy source of an internal combustion engine and with a second heat energy source of the internal combustion engine for the transfer of heat energy from the first heat energy source to the second heat energy source;

an intermediary heat exchanger arranged in heat communication with the second heat energy source heated in the first heat exchanger and with a working fluid of the system for the transfer of heat energy from the second heat energy source to the working fluid of the system;

a turbine arranged in fluid communication with the working fluid heated in the intermediary heat exchanger for the expansion of the working fluid to produce shaft power;

a second heat exchanger arranged in heat communication, via fluid communication, with the expanded working fluid to remove waste heat therefrom and transfer it to an external source such as the atmosphere; and a first compressor arranged in fluid communication with the working fluid exiting the second heat exchanger for increasing the pressure of the cooled working fluid prior to its entry into the intermediary heat exchanger, wherein the working fluid of the system is a substantially supercritical fluid, at least prior to its entry into the turbine; and a recuperator arranged in heat communication, via fluid communication, with the working fluid upon its exit from the internal combustion engine for the transfer of heat energy to the working fluid prior to its entry into the first heat exchanger.

[0013] The system has the advantage that a supercritical working fluid has a high density which allows the system to operate at a high working temperature and pressure in comparison to a steam Rankine cycle, causing a high speed of rotation of the turbine blades. This increases the amount of shaft power produced by the turbine for its size and weight.

[0014] Preferably, the working fluid is supercritical carbon dioxide. Alternatively, the working fluid is supercritical water or other refrigerants.

[0015] Preferably, the system includes a generator operatively associated with the turbine for converting the shaft power produced by the turbine into electrical power. The generator can be substantially smaller than may be required in a Rankine cycle based energy recovery system by virtue of the increased shaft power generated by the turbine.

[0016] Preferably, the system includes a battery adapted for storing the electrical power generated by the generator.

[0017] Preferably, the at least one or first heat energy source of the internal combustion engine is exhaust gas.

[0038] In an alternative embodiment, the recuperator is arranged in heat communication, preferably fluid communication, with the working fluid upon its exit from the first compressor for the transfer of heat energy to the working fluid prior to its entry into the intermediary heat exchanger. More preferably, the recuperator is also arranged in heat communication, preferably fluid communication, with the expanded working fluid for the transfer of heat energy from the working fluid prior to its entry into the second heat exchanger.

[0039] There is further disclosed herein an internal combustion engine heat energy recovery system, comprising:

an internal combustion engine heat exchanger arranged in heat communication with at least one component of the internal combustion engine for the transfer of heat energy from the at least one component of the internal combustion engine to a working fluid of the system, a first heat exchanger arranged in heat communication, via fluid communication, with the working fluid heated by the internal combustion heat exchanger and in heat communication, via fluid communication, with at least one further heat energy source of the internal combustion engine for the transfer of heat energy from the heat energy source to the working fluid of the system;

a turbine arranged in fluid communication with the working fluid heated in the first heat exchanger for the expansion of the working fluid to produce shaft power;

a recuperator arranged in fluid communication with the expanded working fluid from the turbine to recuperate the heat therein, and further being arranged in fluid communication with the working fluid heated by the internal combustion engine heat exchanger to cool the working fluid prior to its entry into the first heat exchanger;

a second heat exchanger arranged in fluid communication with the working fluid heated in the recuperator for the removal of waste heat therefrom and transfer it to an external source such as the atmosphere; and

a first compressor arranged in fluid communication with the working fluid exiting the second heat exchanger for increasing the pressure of the cooled working fluid prior to its entry into the internal combustion engine heat exchanger, wherein the working fluid of the system is a supercritical fluid.

[0040] Preferably, the internal combustion engine heat exchanger is or includes a conduit arranged in heat communication with the at least one component of the internal combustion

engine. Preferably, the conduit is arranged to transport the working fluid through the internal combustion engine.

[0041] Preferably, the system further includes a third heat exchanger in fluid communication with the working fluid exiting the first compressor, in which the working fluid passing through the third heat exchanger is in heat communication with ambient air for cooling the working fluid. Preferably, the system further comprises a second compressor in fluid communication with an air supply and a first intercooler arranged for cooling compressed air exiting the second compressor, wherein the cooled compressed air is in heat communication with the working fluid exiting the third heat exchanger for cooling the compressed air prior to its entry into the internal combustion engine.

[0042] Preferably, the internal combustion engine heat exchanger is located inside the internal combustion engine. Preferably, the at least one engine component is either a combustion cylinder or engine oil.

[0043] Preferably, the second heat exchanger transfers the waste heat from the working fluid to the atmosphere.

[0044] There is further disclosed herein an internal combustion engine heat energy recovery system, comprising:

a first heat exchanger arranged in heat communication, via fluid communication, with at least one heat energy source of an internal combustion engine and with a working fluid of the system for the transfer of heat energy from the heat energy source to the working fluid of the system;

a turbine arranged in fluid communication with the working fluid heated in the first heat exchanger for the expansion of the working fluid to produce shaft power;

a second heat exchanger arranged in heat communication, via fluid communication, with the expanded working fluid to remove waste heat therefrom and transfer it to the atmosphere; and a first compressor arranged in fluid communication with the working fluid exiting the heat exchanger for increasing the pressure of the cooled working fluid prior to its entry into the first heat exchanger, wherein the working fluid of the system is a substantially supercritical fluid.

[0045] There is disclosed herein an internal combustion engine heat energy recovery system, comprising:

a first heat exchanger arranged in heat communication, via fluid communication, with at least one heat energy source of an internal combustion engine and with a working fluid of the system for the transfer of heat energy from the heat energy source to the working fluid of the system;

a turbine arranged in fluid communication with the working fluid heated in the first heat exchanger for the expansion of the working fluid to produce shaft power;

a second heat exchanger arranged in heat communication, via fluid communication, with the expanded working fluid to remove waste heat therefrom and transfer it to the atmosphere; and a first pressurising device arranged in fluid communication with the working fluid exiting the heat exchanger for increasing the pressure of the cooled working fluid prior to its entry into the first heat exchanger, wherein the working fluid of the system is a substantially supercritical fluid.

[0046] In an embodiment, the pressurising device is a heat pump.

[0047] Preferably, the working fluid is supercritical at least prior to its entry into the turbine.

Brief Description of Drawings

[0048] Preferred forms of the present invention will now be described, by way of example only, with reference to the accompanying drawings wherein:

[0049] Figure 1 is a schematic of a first embodiment of the internal combustion engine heat energy recovery system in which heat is recovered from the engine exhaust gas and converted to perform useful work;

[0050] Figure 2 is a schematic of a second embodiment of the internal combustion engine heat energy recovery system in which heat is recovered from the engine coolant and converted to perform useful work;

[0051] Figure 3 is a schematic of a third embodiment of the internal combustion engine heat energy recovery system in which heat is recovered from the engine oil and converted to perform useful work;

CLAIMS

1. An internal combustion engine heat energy recovery system, comprising:

a first heat exchanger arranged in heat communication, via fluid communication, with at least one heat energy source of an internal combustion engine and with a working fluid of the system for the transfer of heat energy from the heat energy source to the working fluid of the system;

a turbine arranged in fluid communication with the working fluid heated in the first heat exchanger for the expansion of the working fluid to produce shaft power;

a second heat exchanger arranged in heat communication, via fluid communication, with the expanded working fluid to remove waste heat therefrom and transfer it to an external source such as the atmosphere; and a first compressor arranged in fluid communication with the working fluid exiting the second heat exchanger for increasing the pressure of the cooled working fluid prior to its entry into the first heat exchanger, wherein the working fluid of the system is a supercritical fluid, at least prior to its entry into the turbine; and

a recuperator arranged in heat communication, via fluid communication, with the working fluid upon its exit from the internal combustion engine for the transfer of heat energy to the working fluid prior to its entry into the first heat exchanger.

2. An internal combustion engine heat energy recovery system, comprising:

a first heat exchanger arranged in heat communication, via fluid communication, with a first heat energy source of an internal combustion engine and with a second heat energy source of the internal combustion engine for the transfer of heat energy from the first heat energy source to the second heat energy source;

an intermediary heat exchanger arranged in heat communication with the second heat energy source heated in the first heat exchanger and with a working fluid of the system for the transfer of heat energy from the second heat energy source to the working fluid of the system;

a turbine arranged in fluid communication with the working fluid heated in the intermediary heat exchanger for the expansion of the working fluid to produce shaft power;

a second heat exchanger arranged in heat communication, via fluid communication, with the expanded working fluid to remove waste heat therefrom and transfer it to an external source such as the atmosphere; and a first compressor arranged in fluid communication with the

working fluid exiting the second heat exchanger for increasing the pressure of the cooled working fluid prior to its entry into the intermediary heat exchanger, wherein the working fluid of the system is a substantially supercritical fluid, at least prior to its entry into the turbine; and

a recuperator arranged in heat communication, via fluid communication, with the working fluid upon its exit from the internal combustion engine for the transfer of heat energy to the working fluid prior to its entry into the first heat exchanger.

3. The internal combustion engine heat energy recovery system of claim 1 or claim 2, wherein the working fluid is supercritical carbon dioxide or supercritical water or other refrigerant.

4. The internal combustion engine heat energy recovery system of any one of claims 1 to 3, wherein the system includes a generator operatively associated with the turbine for converting the shaft power produced by the turbine into electrical power.

5. The internal combustion engine heat energy recovery system of claim 4, wherein the system includes a battery adapted for storing the electrical power generated by the generator.

6. The internal combustion engine heat energy recovery system of any one of claims 1 to 5, wherein the at least one or first heat energy source of the internal combustion engine is exhaust gas.

7. The internal combustion engine heat energy recovery system of any one of claims 1 to 6, wherein the at least one heat energy source or second heat energy source of the internal combustion engine is engine coolant.

8. The internal combustion engine heat energy recovery system of claim 7, wherein the system includes a coolant recirculation conduit arranged to recirculate engine coolant cooled by the first heat exchanger back to the internal combustion engine.

9. The internal combustion engine heat energy recovery system of claim 8, wherein the coolant recirculation conduit is arranged to recirculate the engine coolant in a water circuit inside

the engine and preferably wherein a water circuit is arranged inside the engine for circulation of the working fluid.

10. The internal combustion engine heat energy recovery system of any one of claims 1 to 9, wherein the at least one or first heat energy source of the internal combustion engine is engine oil, preferably wherein the system includes an engine oil recirculation conduit arranged to recirculate engine oil cooled by the first heat exchanger back to the internal combustion engine, and preferably wherein the engine oil recirculation conduit is arranged to recirculate engine oil back inside the engine in an oil circuit.

11. The internal combustion engine heat energy recovery system of any one of claims 1 to 10, wherein the at least one heat energy source is condenser heat emitted by the air conditioning system of a vehicle.

12. The internal combustion engine heat energy recovery system of any one of claims 1 to 11, wherein the system is arranged to recover heat energy from a plurality of heat energy sources of the internal combustion engine, preferably wherein the first heat exchanger is arranged in heat communication, especially via fluid communication, with each of a first heat energy source in the form of engine exhaust gas and a second heat energy source in the form of engine coolant, preferably wherein the first heat exchanger comprises an exhaust gas receiving heat exchanger for the transfer of heat energy from the exhaust gas to the working fluid, and a coolant receiving heat exchanger for the transfer of heat energy from the engine coolant to the working fluid, and preferably wherein the first heat exchanger further includes an oil receiving heat exchanger arranged in heat communication, especially via fluid communication, with a further heat energy source in the form of engine oil for the transfer of heat energy from the engine oil to the working fluid.

13. The internal combustion engine heat energy recovery system of any one of claims 1 to 12, wherein the first compressor is operatively associated with an output shaft of the turbine so as to be driven by the turbine.

14. The internal combustion engine heat energy recovery system of any one of claims 5 to 12, wherein the system includes a motor arranged to draw electrical power from the battery, wherein the first compressor is operatively associated with and driven by the motor.

15. The internal combustion engine heat energy recovery system of any one of claims 1 to 12, in which the first compressor is driven by shaft power produced by the internal combustion engine.

16. The internal combustion engine heat energy recovery system of claim 4, wherein the first compressor is driven directly by the electrical power generated by the generator.

17. The internal combustion engine heat energy recovery system of claim 4, wherein the system further includes a digitally controlled motor device with storage arranged to draw electrical power from the generator.

18. The internal combustion engine heat energy recovery system of claim 17, wherein the digitally controlled motor device comprises a fly wheel for the storage of mechanical power, preferably wherein the digitally controlled motor device further includes a rotor arranged in magnetic communication with the fly wheel, preferably wherein the fly wheel and the rotor are adapted to operate at different speeds of rotation.

19. The internal combustion engine heat energy recovery system of either one of claims 17 or 18, wherein at least a portion of electrical power generated by the digitally controlled motor device is employed to drive the first compressor.

20. The internal combustion engine heat energy recovery system of either one of claims 17 or 18 when dependent upon claim 5, wherein the digitally controlled motor device is arranged to divert at least a portion of electrical power generated therein to the battery for storage.

21. The internal combustion engine heat energy recovery system of either one of claims 1 to 20, wherein the system further includes a second compressor in fluid communication with an air supply and a first intercooler arranged for cooling compressed air exiting the second compressor,

wherein the cooled compressed air is arranged in fluid communication with an intake of the internal combustion engine.

22. The internal combustion engine heat energy recovery system of claim 21, wherein a portion of the working fluid cooled by the second heat exchanger is diverted through the intercooler prior to its entry into the first compressor for cooling the compressed air.

23. The internal combustion engine heat energy recovery system of claim 21, wherein the system includes a second intercooler in heat communication, via fluid communication, with the first intercooler, the first intercooler and second intercooler being arranged in a closed loop through which an intercooler fluid flows, wherein a portion of the working fluid cooled by the second heat exchanger is diverted through the second intercooler for heat exchange with the intercooler fluid prior to its entry into the first compressor, preferably wherein the intercooler fluid is water.

24. The internal combustion engine heat energy recovery system of claim 21 when dependent upon claim 4, wherein the second compressor is driven directly by electrical power generated by the generator.

25. The internal combustion engine heat energy recovery system of claim 21 when dependent upon claim 5, wherein the second compressor is driven by a motor powered by electrical power stored in the battery.

26. The internal combustion engine heat energy recovery system of any one of claims 6 to 23 when dependent upon claim 5, wherein the system further includes a motor generator powered by a portion of the electrical power stored in the battery, wherein the motor generator is operatively associated with a drive shaft of a vehicle powered by the internal combustion engine, preferably wherein the motor generator is adapted to draw electrical power from the battery to rotate a drive shaft of the vehicle.

27. The internal combustion engine heat energy recovery system of any one of claims 21 to 26 when dependent upon claim 25, wherein a portion of the electrical power generated by the digital

gearbox motor is used to drive the first compressor and another portion of the electrical power is used to drive the second compressor.

28. The internal combustion engine heat energy recovery system of any one of claims 20 to 27 when dependent upon claim 6, further including a first digitally controlled motor device with storage arranged in operable communication with both the turbine and the first compressor for driving the first compressor and further includes a second digitally controlled motor device with storage operatively associated with the drive shaft of the vehicle and adapted to draw electrical power from the battery to rotate the drive shaft of the vehicle.

29. The internal combustion engine heat energy recovery system of any one of claims 1 to 28, wherein the working fluid is circulated through the internal combustion engine in heat communication with at least one engine component for the transfer of heat energy from the at least one engine component to the working fluid prior to its entry into the first heat exchanger, preferably wherein the at least one engine component is a combustion cylinder and preferably wherein the at least one engine component is engine oil.

30. The internal combustion engine heat energy recovery system of claim 1 or claim 2, wherein the recuperator is also arranged in heat communication, via fluid communication, with the expanded working fluid for the transfer of heat energy from the working fluid prior to its entry into the second heat exchanger.

31. The internal combustion engine heat energy recovery system of claim 2, wherein the recuperator is arranged in heat communication, via fluid communication, with the working fluid upon its exit from the first compressor for the transfer of heat energy to the working fluid prior to its entry into the intermediary heat exchanger.

32. The internal combustion engine heat energy recovery system of claim 31, wherein the recuperator is also arranged in heat communication, via fluid communication, with the expanded working fluid for the transfer of heat energy from the working fluid prior to its entry into the second heat exchanger.

33. An internal combustion engine heat energy recovery system, comprising:

an internal combustion engine heat exchanger arranged in heat communication with at least one component of the internal combustion engine for the transfer of heat energy from the at least one component of the internal combustion engine to a working fluid of the system, a first heat exchanger arranged in heat communication, via fluid communication, with the working fluid heated by the internal combustion heat exchanger and in heat communication, via fluid communication, with at least one further heat energy source of the internal combustion engine for the transfer of heat energy from the heat energy source to the working fluid of the system;

a turbine arranged in fluid communication with the working fluid heated in the first heat exchanger for the expansion of the working fluid to produce shaft power;

a recuperator arranged in fluid communication with the expanded working fluid from the turbine to recuperate the heat therein, and further being arranged in fluid communication with the working fluid heated by the internal combustion engine heat exchanger to cool the working fluid prior to its entry into the first heat exchanger;

a second heat exchanger arranged in fluid communication with the working fluid heated in the recuperator for the removal of waste heat therefrom and transfer it to an external source such as the atmosphere; and

a first compressor arranged in fluid communication with the working fluid exiting the second heat exchanger for increasing the pressure of the cooled working fluid prior to its entry into the internal combustion engine heat exchanger, wherein the working fluid of the system is a supercritical fluid.

34. The internal combustion engine heat energy recovery system of claim 33, wherein the internal combustion engine heat exchanger is or includes a conduit arranged in heat communication with the at least one component of the internal combustion engine, preferably wherein the conduit is arranged to transport the working fluid through the internal combustion engine.

35. The internal combustion engine heat energy recovery system of claim 33, further including a third heat exchanger in fluid communication with the working fluid exiting the first compressor, in which the working fluid passing through the third heat exchanger is in heat communication with ambient air for cooling the working fluid, and preferably further comprising

a second compressor in fluid communication with an air supply and a first intercooler arranged for cooling compressed air exiting the second compressor, wherein the cooled compressed air is in heat communication with the working fluid exiting the third heat exchanger for cooling the compressed air prior to its entry into the internal combustion engine, preferably wherein the internal combustion engine heat exchanger is located inside the internal combustion engine, and preferably wherein the at least one engine component is either a combustion cylinder or engine oil.

36. The internal combustion engine heat energy recovery system of any one of claims 33 to 35, wherein the second heat exchanger is arranged to transfer the waste heat from the working fluid to the atmosphere.

37. An internal combustion engine heat energy recovery system, comprising:

a first heat exchanger arranged in heat communication, via fluid communication, with at least one heat energy source of an internal combustion engine and with a working fluid of the system for the transfer of heat energy from the heat energy source to the working fluid of the system;

a turbine arranged in fluid communication with the working fluid heated in the first heat exchanger for the expansion of the working fluid to produce shaft power;

a second heat exchanger arranged in heat communication, via fluid communication, with the expanded working fluid to remove waste heat therefrom and transfer it to the atmosphere; and a first compressor arranged in fluid communication with the working fluid exiting the heat exchanger for increasing the pressure of the cooled working fluid prior to its entry into the first heat exchanger, wherein the working fluid of the system is a substantially supercritical fluid.

38. An internal combustion engine heat energy recovery system, comprising:

a first heat exchanger arranged in heat communication, via fluid communication, with at least one heat energy source of an internal combustion engine and with a working fluid of the system for the transfer of heat energy from the heat energy source to the working fluid of the system;

a turbine arranged in fluid communication with the working fluid heated in the first heat exchanger for the expansion of the working fluid to produce shaft power;

a second heat exchanger arranged in heat communication, via fluid communication, with the expanded working fluid to remove waste heat therefrom and transfer it to the atmosphere; and a first pressurising device arranged in fluid communication with the working fluid exiting the heat exchanger for increasing the pressure of the cooled working fluid prior to its entry into the first heat exchanger, wherein the working fluid of the system is a substantially supercritical fluid.

39. The internal combustion engine heat energy recovery system of claim 38, wherein the pressurising device is a heat pump.