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(54) **AN ELECTRIC TURBOMACHINE**

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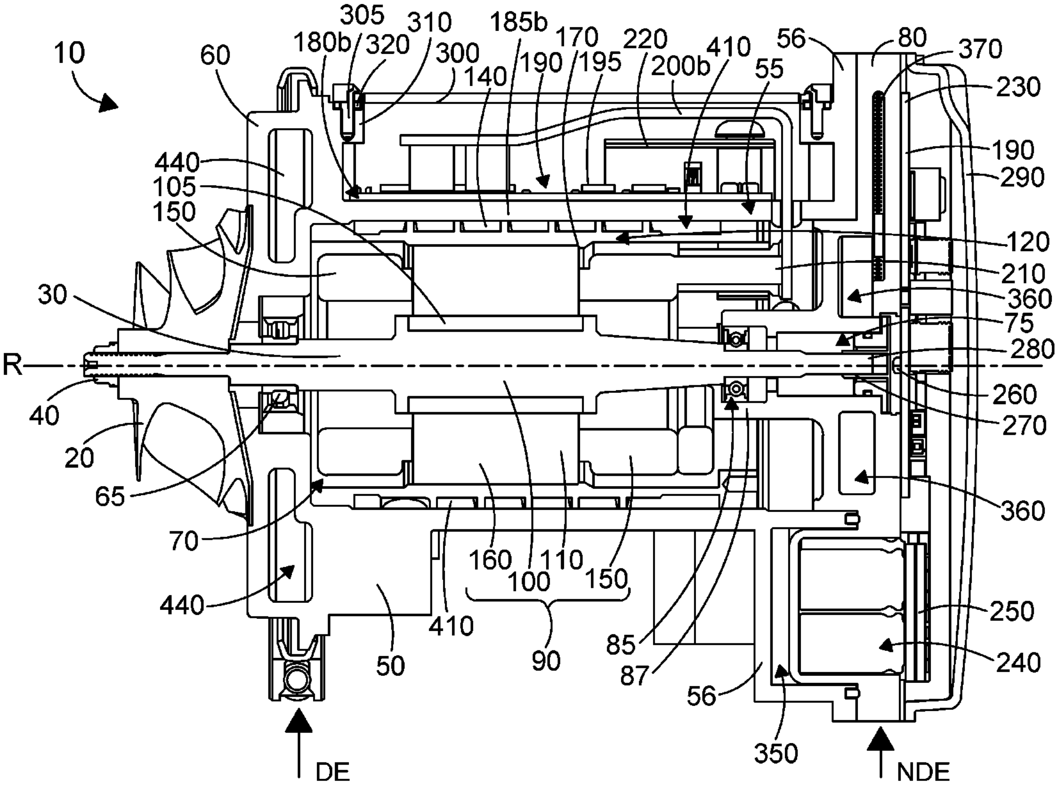
(57) **ABSTRACT**

An electric turbomachine for use with an internal combustion engine, turbocharger or a fuel cell e-compressor, said electric turbomachine comprising: a compressor (**20**) that is arranged to compress fluid within a turbo compressor when it is rotationally driven about a rotational axis (R) by a shaft, said shaft being rotational supported by a drive-end bearing (**65**) and a non-drive-end bearing (**85**), and a high-speed electrical machine located within a housing (**50**) that is arranged to rotationally drive the shaft about the rotational axis (R); said housing comprising a drive-end wall (**60**) that the shafts extends through to rotationally drive the compressor, a non-drive- end wall (**80**) at the opposing end of the electric turbomachine to the compressor, and a side wall (**55**) that extends between the drive-end wall and the non-drive-end wall, and wherein the electric turbomachine comprises a cooling system (**330**), for receiving a flow of a coolant fluid to cool the electric turbomachine, that is integrated within the housing of the electric turbomachine.



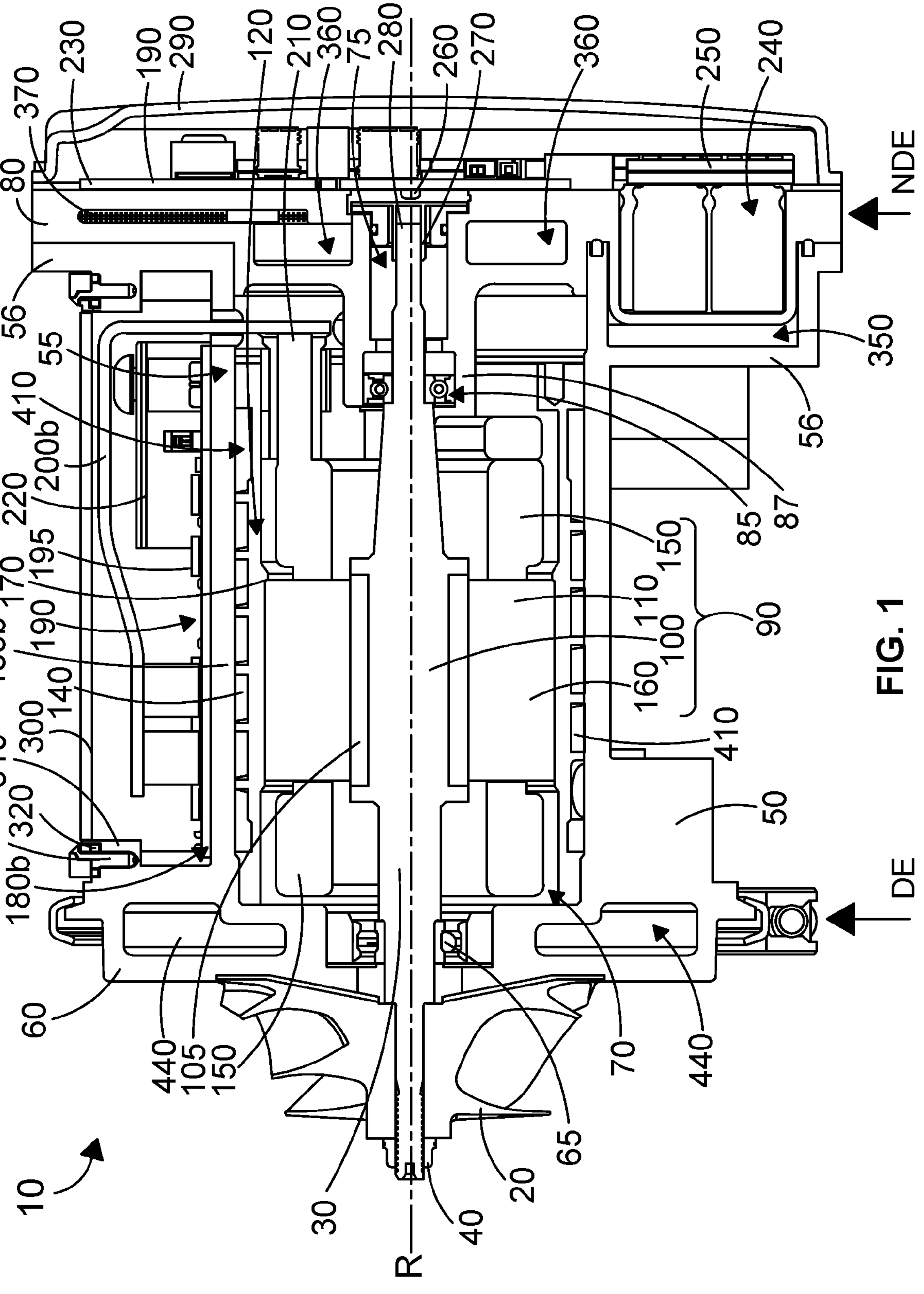

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FIG. 1

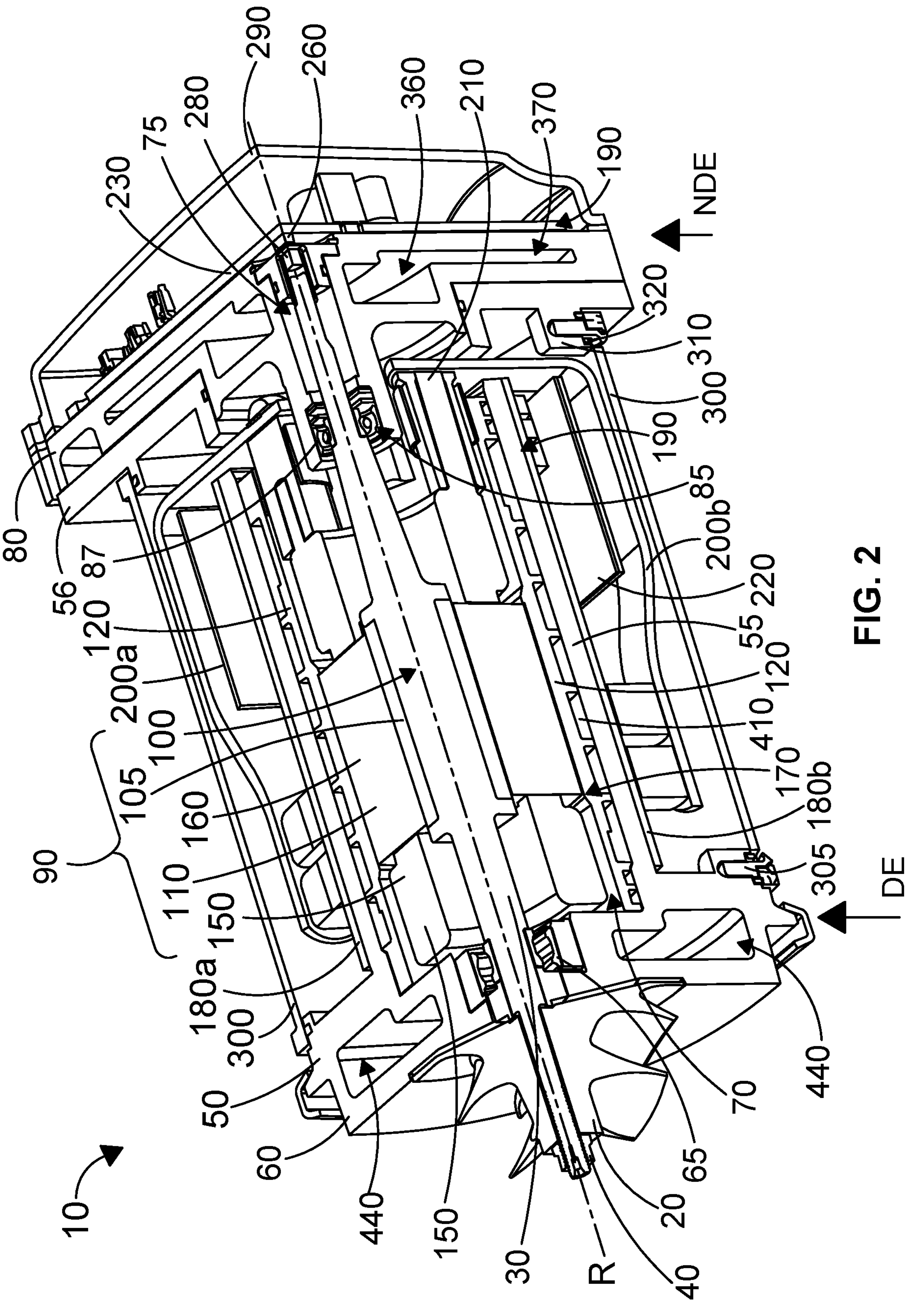
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FIG. 2

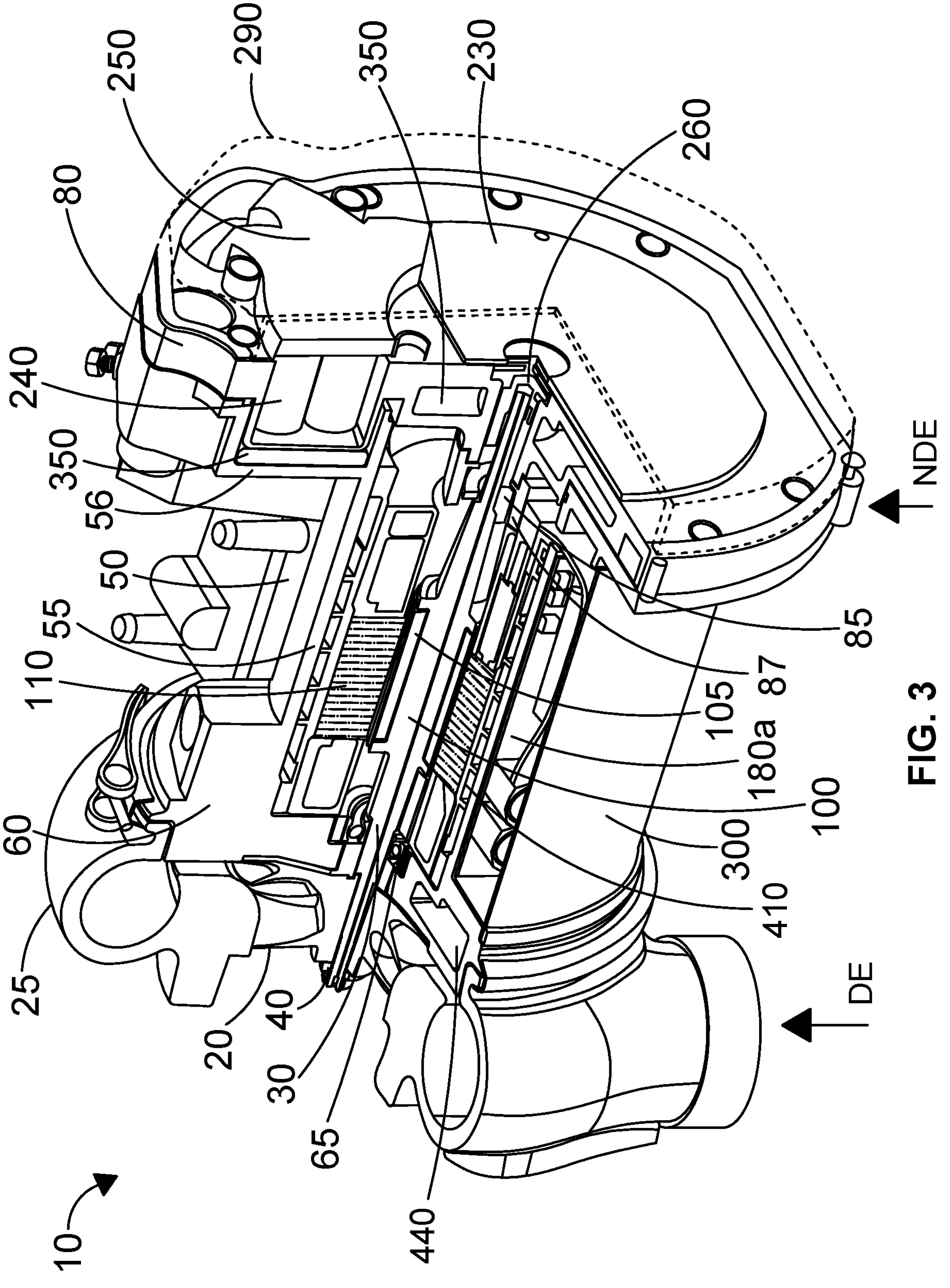
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FIG. 3

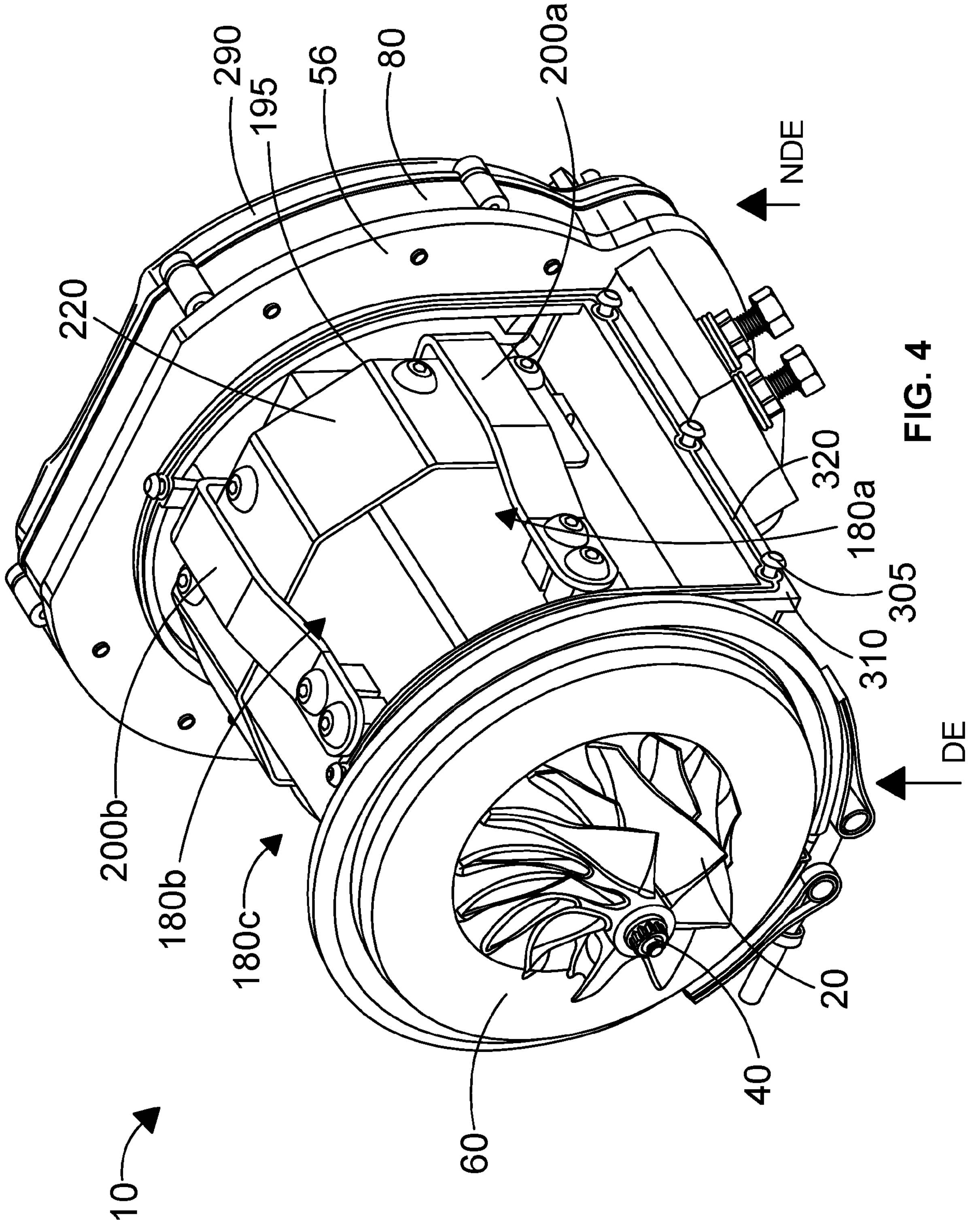
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FIG. 4

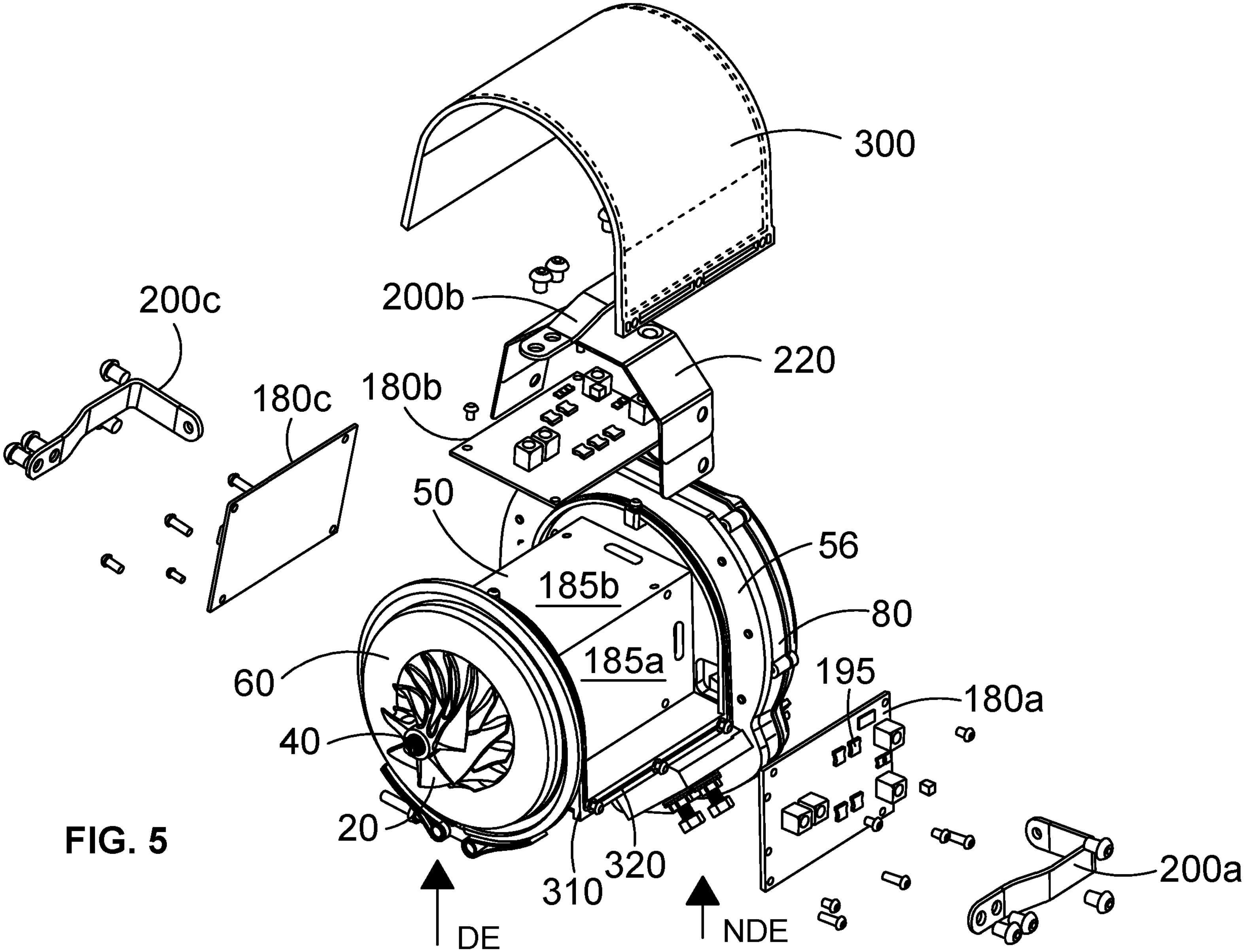
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FIG. 5

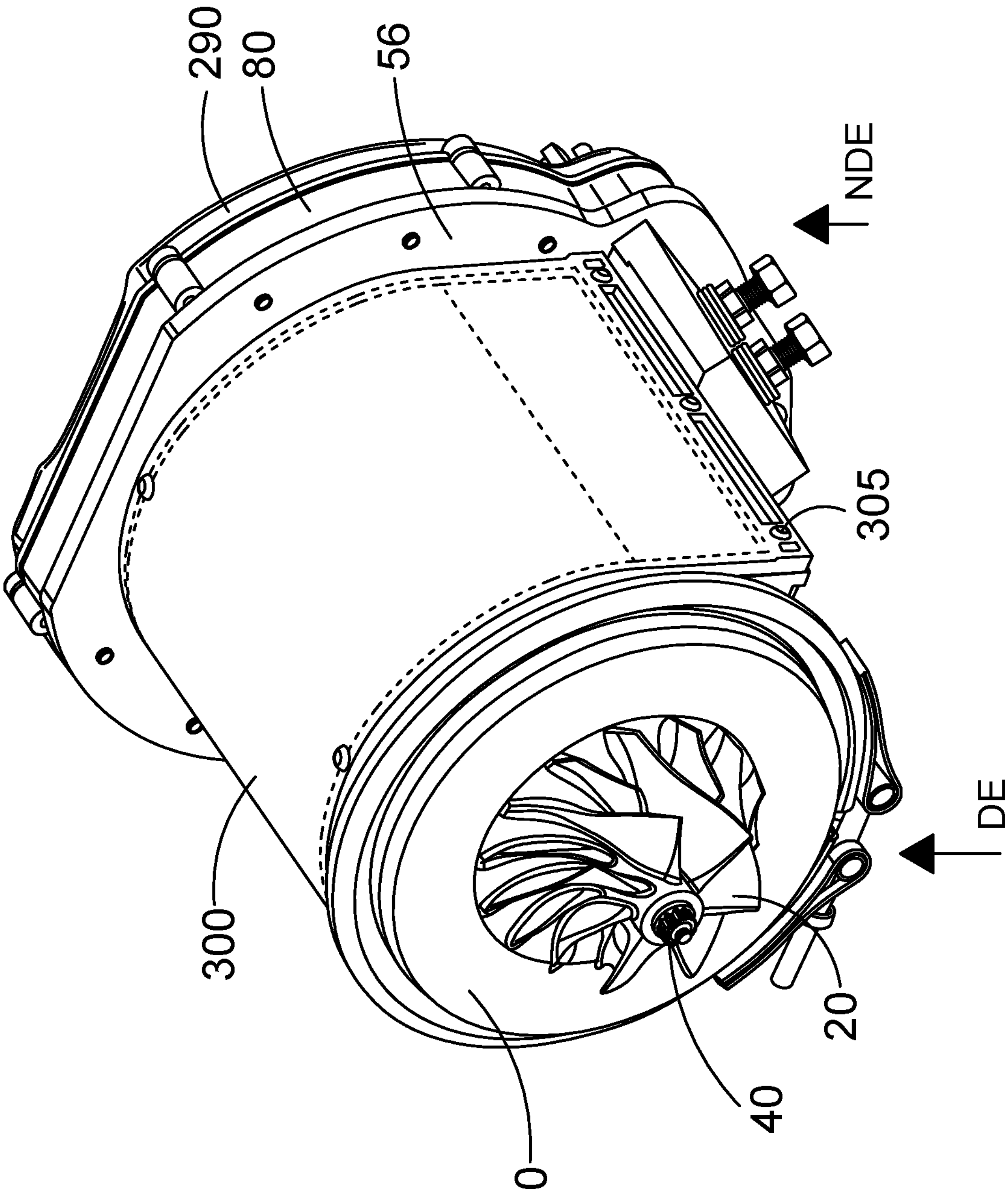

FIG. 6

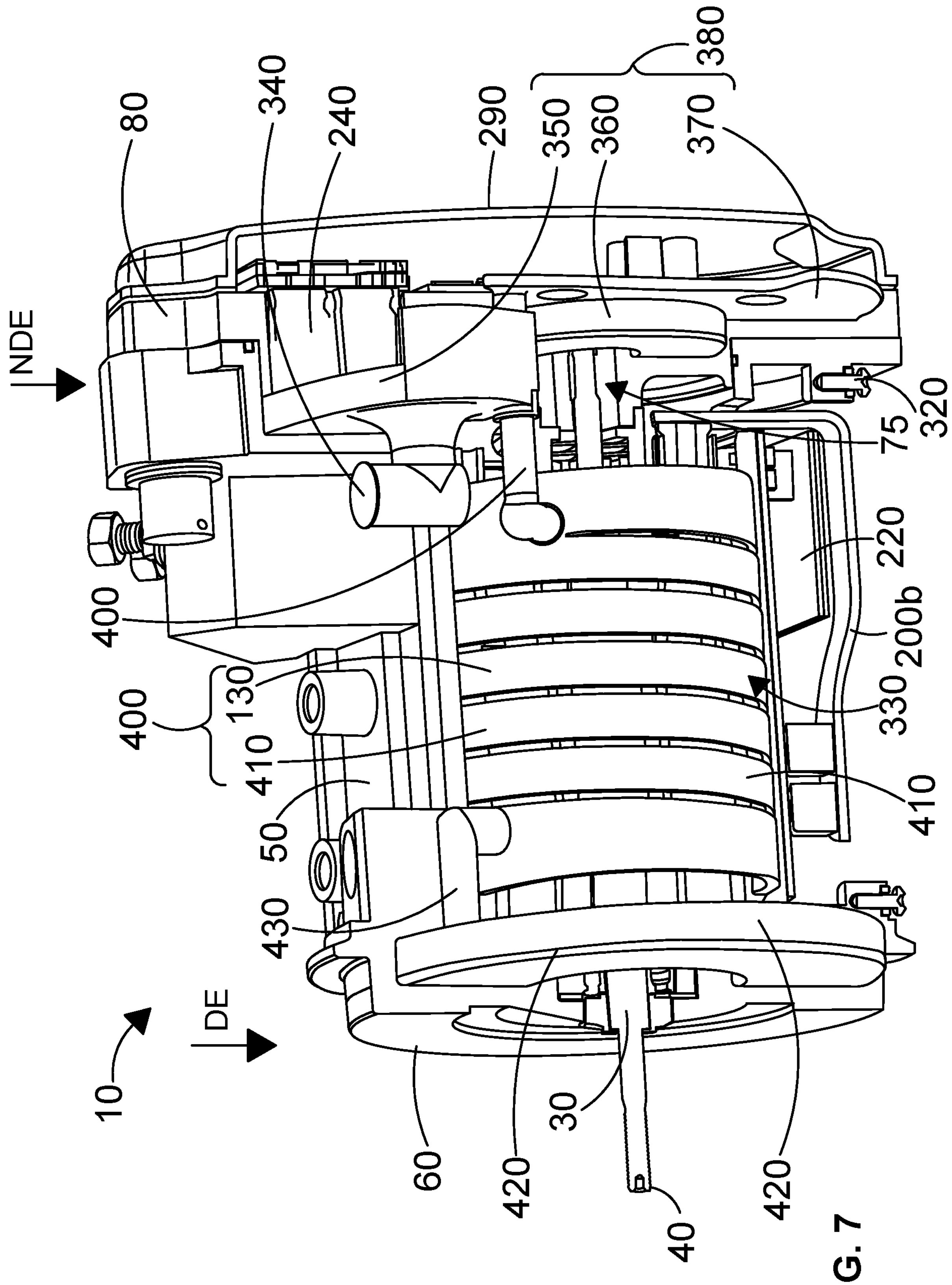
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FIG. 7

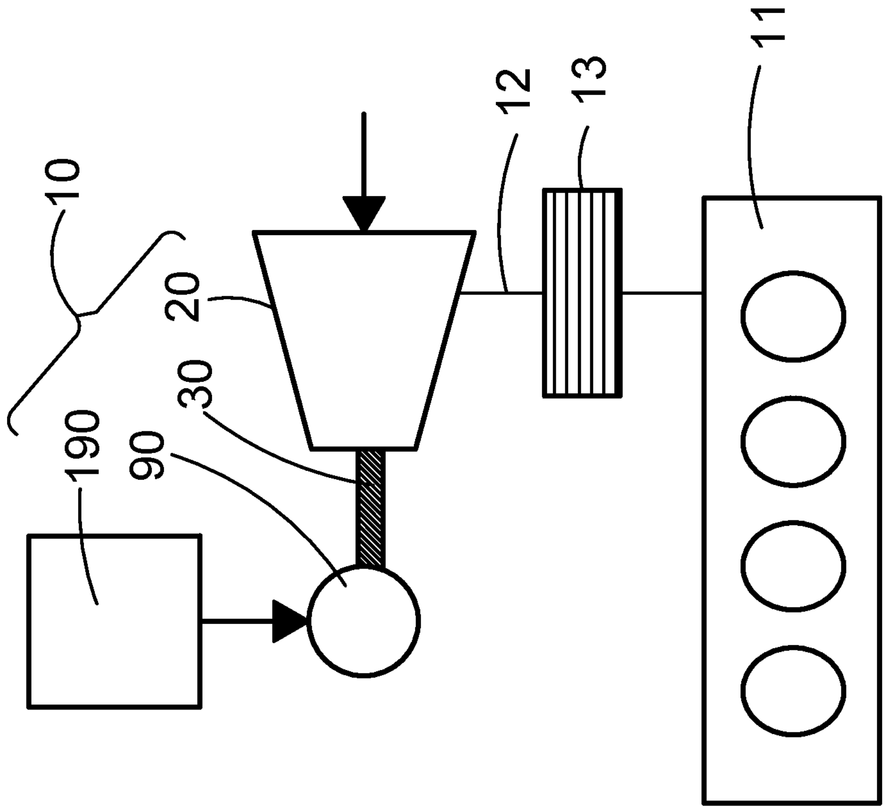

FIG. 8

AN ELECTRIC TURBOMACHINE

FIELD OF THE INVENTION

[0001] The present invention relates to an electric turbomachine for use with an internal combustion engine, turbocharger or a fuel cell e-compressor, and more particularly to an electric turbomachine comprising a cooling system that is integrated within the housing of the electric turbomachine.

BACKGROUND TO THE INVENTION

[0002] Regulations and a need to combat climate change continue to push internal combustion engines to have both lower emissions and greater efficiency. However, the need to optimise the operation of engines in vehicles further at key running points still remains a challenge in this field. Many existing applications use a turbocharger, where the energy contained within exhaust gases is extracted via a turbine connected to a compressor housing to improve the power density and thermal efficiency of an engine. Additionally, there is a latent need to improve the efficiency of other internal combustion engines such as stationary gensets and air handling systems for feeding fuel-cells.

[0003] Aerodynamic matching of the exhaust driven turbocharger turbine, or compressor, involves a compromise between transient response at low load and power targets at high load. Due to this trade off, the drive for ultimate efficiency at certain running points can in turn adversely impact running points at other engine running conditions, which is undesirable both from a driver satisfaction and an engine emissions viewpoint.

[0004] One of the possible solutions to this problem is to provide electrified turbomachinery or electric turbomachines, which are known as an electric compressor or electric supercharger, to provide additional boost pressure.

[0005] In the electric turbomachines, a high-speed electrical machine, such as a permanent magnet synchronous motor, is used, for example, to accelerate the compressor component of the electric turbomachinery to provide additional boost pressure to the engine or to accelerate the compressor of the turbocharger to reduce response times. A high-speed electrical machine is considered to be an electrical machine where the magnetic rotor surface reaches speeds in excess of 80 m/s and even greater than 200 m/s. Typically, if the electrical machine is directly attached to the compressor or another turbomachine then it is classified as high-speed.

[0006] However, several issues with current electrified machinery technology has prevented their wider proliferation within the market. For example, electrified machinery requires power electronics systems to convert the direct current (DC) available from the vehicle's power system to the alternating current (AC) required to power suitable high-speed electrical machines such as permanent magnet synchronous motors. The power electronic systems typically comprise both power printed circuit board assemblies (power PCBA) and control printed circuit board assemblies (control PCBA). Both of these PCBAs comprise heat sensitive components and components that generate substantial heat such as capacitors and transistors. Accordingly, the power PCB and the control PCB typically require complex, separate cooling systems. These cooling systems not only thermally protect the power PCBA and the control PCBA by removing heat, or cooling, that they themselves generate, but the cooling systems also remove heat emitted by electric turbomachine (e.g. from the high-speed electrical machine and the heat of the compressed fluids of the compressor) and the high-ambient temperatures that are produced by the internal combustion engine itself.

[0007] The cooling systems are typically dedicated water-cooled jackets or heat sinks for cooling individual components or component groups. For example, a dedicated water-cooled jacket, radiator and pump can be included to cool the power electronics assembly and a separate water-cooled jacket, radiator and pump can be included to cool the electrical machine of the electric turbomachine. However, the inclusion of these dedicated water-cooled jackets or heat sinks is undesirable due to their size, weight, reliability, lifetime and maintenance.

[0008] Additionally, electric turbomachine applications require a very high lifetime requirement, without component replacement, to be economically and practically viable. As such, it is important that all components of the electric turbomachine, such as the electrical machine, power PCBA and control PCBA are kept below their heat rating. Thus, providing adequate cooling to the electric turbomachine and its associated components is a key factor in their design.

[0009] An additional problem associated with the power electronics of electric turbomachines is that the provision of the power PCBA and the control PCBA and their cooling systems typically increases the footprint and weight of the electric turbomachine to such a degree that incorporating the electric turbomachine in close proximity with the internal combustion engine of the vehicle, as is required for optimal performance, is challenging. Further, they are tight constraints on space envelope, for packaging purposes. As such, decreasing the size of components or eliminating them entirely is desirable.

[0010] In the state of the art, power electronics assemblies are installed separately away from the electric turbomachine and, for example, the internal combustion engine. This makes it possible to enable operation of the power electronics systems (i.e. the control PCBA and the power PCBA) within a cooler and more benign environment. This have the benefit of having a reduced cooling demand and may allow the design of more compact power PCBAs and control PCBAs. However, the applicant has found this approach to be disadvantageous as it requires at least one additional cooling circuit, additional electrical power, additional electrical signals and additional mounting features. These additional features plus their requisite (electrical & coolant) connections and environmental sealing requirements increase the installation complexity, maintenance complexity, size, weight and associated failure modes of the electric turbomachine.

[0011] One solution is to produce a more compact implementation of design and separate features that could be accommodated within the space allocation. However, the applicant has found that the drawbacks of this method, such as the complex manufacturing techniques and increased costs are disproportionately large to the advantages.

[0012] Another problem with state of the art turbomachines is that the stator of the electrical machine self-generates a large amount of heat; if this heat is not removed efficiently then the heat that it emits can cause very short component lifetime.

[0013] Objects and aspects of the present invention seek to alleviate at least these problems with the prior art.

SUMMARY OF THE INVENTION

[0014] According to the present invention there is provided an electric turbomachine for use with an internal combustion engine, turbocharger or a fuel cell e-compressor, said electric turbomachine comprising: a compressor that is arranged to compress fluid within a turbo compressor when it is rotationally driven about a rotational axis (R) by a shaft, said shaft being rotational supported by a drive-end bearing and a non-drive-end bearing, and a high-speed electrical machine located within a housing that is arranged to rotationally drive the shaft about the rotational axis (R); said housing comprising a drive-end wall that the shafts extends through to rotationally drive the compressor, a non-drive-end wall at the opposing end of the electric turbomachine to the compressor, and a side wall that extends between the drive-end wall and the non-drive-end wall, and wherein the electric turbomachine comprises a cooling system, for receiving a flow of a coolant fluid to cool the electric turbomachine, that is integrated within the housing of the electric turbomachine.

[0015] The cooling system (or as it may also be known the cooling circuit) is integrated within the housing in that the coolant fluid used to cool the electric turbomachine in use flows through the inside walls of housing of the electric turbomachine. That is, the housing that usually surrounds the electrical machine of the electric turbomachine comprises cavities, holes, apertures, conduits or the like for receiving a flow of coolant fluid to cool the electric turbomachine. In general, housings of the electric turbomachines are fabricated from metal so the housing possess good or excellent thermal conductivity. Thus, the housing itself can conduct heat from the heat-generating components of the electric turbomachine to the integrated cooling system. As such, the present invention efficiently uses previously dead or wasted space within the housing and electric turbomachine.

[0016] The fluid that is compressed by the electric turbomachine depends on the use and deployment of the electric turbomachine. Typically, the fluid compressed by the compressor in use is air or exhaust fluids from an internal combustion engine, for example, however other fluids may also be compressed.

[0017] In this way, the cooling system is integrated into the housing of the electric turbomachine and the need to provide separate, independent and/or external cooling systems, such as heat sinks and cooling jackets, is reduced or eliminated altogether. This reduction or elimination of independent, separate and/or external cooling systems beneficially reduces the weight, volume, size, footprint, number of associated failure points and installation and maintenance complexity of electric turbomachine.

[0018] It is envisaged that the coolant fluid will flow through and directly contact the housing such that the coolant fluid will not flow through additional piping inside the housing. However, it is also envisaged that the cooling system may optionally comprise corrosion or rust resistant inserts or sheaths that also possess high thermal conductivity such as galvanised steel or brass.

[0019] One benefit of this direct contact between the housing and the coolant fluid is that the direct contact reduces and/or minimises the number of interfaces between the heat-generating components and coolant fluid. These interfaces, and in particular air interfaces, limit the rate of heat transfer and are typically present in heat-sinks and cooling jackets for example.

[0020] Additionally, integrated the cooling system into the housing means that, in use, the coolant fluid flows through locations closer to the heat-generating components of electric turbomachine and therefore cool the electric turbomachine more efficiently. Thus, it is envisaged that the rate of flow or the volume of the coolant fluid can be decreased to achieve the same cooling effect. Accordingly, it is envisaged that, in use, the pump used to pump coolant fluid around the cooling system integrated within the housing will be smaller and require less power than a pump for use with an external cooling jacket for example.

[0021] Preferably, the cooling system comprises a drive-end coolant cavity located within the drive-end wall for receiving a flow of coolant fluid to cool the electric turbomachine. In use, the drive-end of the electric turbomachine is typically situated near separate or external heating-generating components such as an internal combustion engine, turbocharger or a fuel cell e-compressor. Additionally, the action of the compressor within the turbo compressor also generates heat proximate to the exterior side of the drive-end wall. Furthermore, the drive-end wall is typically proximate to the drive-end bearing which also generates heat. Moreover, the drive-end wall and drive-end cooling cavity is proximate to the heat-generating high-speed electrical machine. Thus, the drive-end coolant cavity can perform triple-sided cooling for each of the heat-generating components mention above. The cooling system having a drive-end coolant cavity helps to remove heat from the electric turbomachine, thereby protecting heating sensitive components, such as the electrical machine, from all of these sources of heat.

[0022] Preferably, the drive-end coolant cavity encircles the shaft as it extends through the drive-end wall. By encircling the shaft, the drive-end coolant cavity cools an area all around the drive-end wall surrounding the shaft and, thus, prevents the formation of hotspots and provides effective cooling of the drive-end wall. Preferably, the drive-end coolant cavity is torus-shaped or toroid-shaped.

[0023] Preferably, the drive-end coolant cavity is arranged to cool the drive-end bearing. In such embodiments, the drive-end coolant cavity is positioned close enough to the drive-end bearing to absorb the heat generated by the drive-end bearing. This is beneficial to prevent the drive-end bearing from overheating and having a decreased lifespan by, for example, damaging the grease in the bearing.

[0024] Preferably, the drive-end coolant cavity encircles the drive-end bearing. By encircling the drive-end bearing, the cooling effect of the drive-end coolant cavity is increased on the drive-end bearing as it ensures the entire circumference of the drive-end bearing is cooled. This prevents the formation of hotspots within the drive-end bearing.

[0025] Preferably, the cooling system comprises a non-drive-end coolant cavity located within the non-drive-end wall for receiving a flow of fluid coolant to cool the electric turbomachine. The non-drive-end wall and non-drive-end cooling cavity are typically proximate to one end of the heat-generating high-speed electrical machine and remove heat generated by the electrical machine. Additionally, the electrical connections that provide power to the electrical machine are typically located at this end and the non-drive-end cooling cavity can also cool these connections, or the area that they are housed within, as well.

[0026] Preferably, the non-drive-end coolant cavity is arranged to cool the non-drive end bearing. In such embodiments, the non-drive-end coolant cavity is positioned close enough to the non-drive-end bearing to absorb the heat generated by the non-drive-end bearing. This is beneficial as it prevents the drive-end bearing from overheating which shortens its lifespan by, for example, damaging the grease in the bearing.

[0027] Preferably, the non-drive-end bearing is located proximate to the non-drive-end wall within a bearing housing and the bearing house is thermally connected to the non-drive-end wall. In this way, the non-drive-end bearing is not situated within the non-drive-end wall. Distancing the non-drive-end bearing from the non-drive-end can be beneficial when a temperature sensitive component, such as a magnet, is incorporated onto the end of the shaft adjacent to the non-drive-end wall.

[0028] Preferably, the non-drive-end coolant cavity encircles the non-drive end of the shaft. By encircling the shaft, the cooling effect on the non-drive-end coolant cavity is increased on the shaft and components connected to or associated with shaft, as it ensures the entire circumference of the shaft is cooled. Preferably, the non-drive-end coolant cavity is torus-shaped or toroid-shaped.

[0029] Preferably, the non-drive-end coolant cavity encircles the non-drive end bearing. By encircling the bearing, the cooling effect on the non-drive-end coolant cavity is increased on the bearing and components connected to or associated with the bearing. Preferably, the non-drive-end coolant cavity is torus-shape or toroid-shaped.

[0030] Preferably, the non-drive-end coolant cavity is arranged to cool a power electronics that are mounted on an exterior surface of the non-drive-end wall. Mounting power electronics assemblies, such as a control printed circuit board, onto the non-drive end wall of the housing is beneficial as it reduces the size of the electric turbomachine and its associated electronics. The power electronics that is mounted in this preferred embodiment, such as the control PCB, generate heat and in the prior art when they are not mounted on the housing they typically have their own independent and separate cooling systems. Furthermore, mounting the power electronics assemblies on the non-drive-end wall exposes the temperature sensitive components of the power electronics to the heat generated by the electric turbomachine. These problems are overcome in this preferred embodiment as the power electronics are cooled by the cooling system and, in particular, by the non-drive-end coolant cavity. This removes the need for an independent and separated cooling system for the power electronics, such as the control printed circuit board, reducing the size and complexity of the electric turbomachine.

[0031] Preferably, the non-drive-end coolant cavity comprises one or more plate-like or disc-like portions that are arranged to cool the power electronics that is mounted on the exterior surface of the non-drive-end wall. Preferably, the largest diameter of the plate-like or disc-like portions extend in a direction parallel with the non-drive-end wall to provide efficient cooling of the mounted power electronics.

[0032] Preferably, the non-end-drive coolant cavity is arranged to cool a control printed circuit board that is mounted on the exterior surface of the non-drive-end wall. Such an arrangement may optionally comprises larger portions of the non-drive-end coolant cavity located proximate to heat generating components of the control printed circuit board, such as the capacitors located on the control printed circuit boards. In this way, the need or size of the independent or separate cooling system used to cool the control printed circuit board is reduced or removed entirely.

[0033] Preferably, the cooling system comprises a side wall coolant cavity located within the side wall for receiving a flow of coolant fluid to cool the electric turbomachine. The side wall and the side wall coolant cavity are typically located adjacent or proximate to heating generating components of the electric turbomachine and can remove heat from these components and the electric turbomachine as a whole.

[0034] Preferably, the side wall coolant cavity is arranged to cool the electrical machine. In this preferred embodiment, the side wall coolant cavity is located close enough within the side wall to extract the heat generated by the high-speed electrical machine. In the prior art the cooling for the electrical machine is located external and removed from the housing. This reduces the effectiveness of the cooling as it is separated by a greater distance and increased number of interfaces from the electrical machine, thereby reducing the efficiency of the electrical machine. Accordingly, the present preferred embodiment is beneficial as it provides an improved rate of cooling of the high-speed electrical machine such that the electrical machine is more efficient.

[0035] Preferably, the side wall coolant cavity encircles the electrical machine. By encircling the electrical machine the side wall coolant cavity provides a cooling effect around the entire circumference of the electrical machine.

[0036] Preferably, the side wall coolant cavity comprises a helical coolant cavity that encircles the electrical machine. The helical coolant cavity is beneficial as it loops through the side wall and around the electrical machine encircling it. This again provides effective cooling around the entire circumference of the electrical machine. Furthermore, the helical configuration of the helical coolant cavity spirals around the electrical machine providing a relatively narrow pathway for the flow of the coolant fluid. Thus, the helical configuration improves circulation and the cooling effect of the coolant fluid by reducing turbulence of the coolant fluid compared to, for example, a simple cylindrical coolant cavity.

[0037] Preferably, the side wall coolant cavity extends along the full length of the electrical machine. By extending along the full length of the machine, the cooling effect of the side wall coolant cavity is experienced by more of the electrical machine. Even more preferably, the helical coolant cavity extends along the full length of the electrical machine. Such a helical coolant cavity provides cooling for the electrical machine both around its entire circumference and its entire length.

[0038] Preferably, the side wall coolant cavity is arranged to cool power electronics that are mounted on an exterior surface of the side wall. Mounting power electronics, such as a power printed circuit board, on the side wall of the housing is beneficial to reduce the size of the electric turbomachine. The power electronics that is mounted in this embodiment, such as the power printed circuit board, generate heat and in the prior art when they are not mounted on the housing they typically have their own independent and separate cooling systems. Furthermore, mounting the power electronics on the side wall exposes the temperature sensitive components of the power electronics to the heat generated by the electric turbomachine. These problems are overcome in this preferred embodiment as the power electronics, e.g. the power printed circuit board, are cooled by the cooling system and, in particular, by the side wall coolant cavity. This removes the need for an independent and separated cooling system for the power electronics, such as the power printed circuit board, reducing the size and complexity of the electric turbomachine.

[0039] Preferably, the side wall coolant cavity is arranged to cool a power printed circuit board that is mounted on the exterior surface of the side wall. In this way, the need or size of the independent or separate cooling system used to cool the power printed circuit board is reduced or removed entirely.

[0040] Preferably, the side wall coolant cavity is arranged to cool a plurality of power printed circuit boards that are mounted on one or more exterior surfaces of the side wall.

[0041] Preferably, the majority of the side wall coolant cavity is formed between an interior surface of the side wall and a surface of a jacket that supports the electrical machine. More preferably, the majority of the side wall coolant cavity is formed between an interior surface of the side wall and one or more channels in the surface of a jacket that supports the electrical machine. Typically, the jacket in an electric turbomachine helps to position the electrical machine within the housing by engaging and supporting the electrical machine and housing. By forming the side wall coolant cavity between the jacket and the side wall, the coolant cavity flows closer to the electrical machine and the cooling effect of the side wall coolant cavity is increased.

[0042] Alternatively, the majority of the side wall coolant cavity is formed within the side wall of the housing. Or, in other words, the jacket for supporting the electrical machine is integrally formed with the housing of the electrical machine. This is beneficial as it reduces the number of components while retaining the advantageous close proximity between the electrical machine and the side wall coolant cavity.

[0043] Preferably, the cooling system comprises a drive-end coolant cavity as described in any of the optional or preferred embodiments above, a non-drive-end cavity as described in any of the optional or preferred embodiments above and a side wall coolant cavity as described in any of the optional or preferred embodiments above. In this way, the benefits of one or more of the coolant cavities can be combined and synergised.

[0044] Preferably, the drive-end coolant cavity, the non-drive-end coolant cavity and the side wall coolant cavity are fluidly connected to one another to form a continuous pathway inside the housing for receiving a flow of coolant fluid to cool the electric turbomachine. In this way, the three coolant cavities are linked and connected to one another. This means that only one set of piping and pump needs to be supplied to generate the flow coolant fluid. As described above, the three coolant cavities each cool various features individually and connecting them together means that they can cool most if not all of the electrical turbomachine and/or have an increased cooling effect on a particular feature of the electric turbomachine. This reduces the size and complexity of cooling systems associated with the electric turbomachine.

[0045] Preferably, the fluid connections between the drive-end coolant cavity, non-drive-end coolant cavity and the side wall coolant cavity are integrated within the drive-end wall, non-drive-end wall and the side wall. The integration of the connections between coolant cavities is beneficial as it minimises the chances of leaks and from, for example, piping connections, helps to minimise the size of the cooling system and improves the cooling effect of the cooling system.

[0046] Preferably, the drive-end coolant cavity is fluidly connected to the side wall coolant cavity, and the side wall coolant cavity is fluidly connected to the non-drive-end coolant cavity. Connecting the coolant cavities in this configuration provides a continuous path for the coolant fluid from the drive-end wall through the side wall to the non-drive-end wall or vice versa.

[0047] Preferably, the cooling system is arranged such that, in use, coolant fluid flows into the cooling system via an inlet into the non-drive-end wall cavity and coolant fluid flows out of the cooling system via an outlet from the drive-end wall cavity. This configuration of the coolant cavities is beneficial as typically the temperature of the turboelectric machine increases from non-drive end across the machine to the drive-end. Accordingly, supplying coolant fluid at the non-drive-end coolant cavity and extracting it from the drive-end coolant cavity means that the coolant fluid flows in the same direction as the temperature gradient of the electric turbomachine, thereby improving the cooling effect of the cooling system.

[0048] Preferably, the cooling system is the only system used to actively cool the electric turbomachine. That is, the cooling system supplies a sufficient cooling effect such that additional active cooling systems, coolant fluid or heat sinks are not required to operate the electric turbomachine. The electric turbomachine may also be cooled passively via normal convention or ambient conditions associated with placing the electric turbomachine in a working environment such as an engine bay. Preferably, the cooling system provides more than 80% of the cooling required by the electric turbomachine. More preferably, the cooling system provides more than 90% of the cooling required by the electric turbomachine.

[0049] Preferably, the electric turbomachine is an electric compressor.

[0050] As discussed above, the power electronics can be mounted onto the housing of the electric turbomachine. It is preferable in such embodiments that the power electronics do not extend beyond the footprint of the electric turbomachine. Reduction in footprint refers to a reduction in the packaging size of the electric turbomachine. These embodiments achieve this by reducing the diameter of the electric turbomachine as the power electronics do not extend beyond the maximum diameter defined by the housing and/or turbo compressor of the electric turbomachine.

[0051] The power electronics may be directly mounted onto the electric turbomachine by splitting the power PCB of the power electronics into three triplicated circuits. Each of the three power PCBs is smaller than a monolithic power PCB, even if cumulatively the size of the three power PCBs is similar to that of a monolithic PCB. However, by using separate and smaller power PCBs, it is possible to arrange these PCBs around the machine, staying within the outline of the machine and, essentially, within the overall confines of the space allocated.

[0052] Furthermore, the control PCB may be integrated onto the non-drive-end and non-drive-end wall of the electric turbomachine. By separating, the control PCB from the power PCB, the size and complexity of the power PCB is reduced such that the power PCB can be more easily incorporated about the housing of the electric turbomachine. Additionally, mounting the control PCB directly onto the non-drive-end and non-drive-end wall enables the control PCB to directly comprise the sensor for detecting the rotational speed of the electrical machine. Removing the need for additional circuitry and failure points.

[0053] Accordingly, these preferred embodiments overcomes the issues associated with using a single monolithic power electronics assembly that the resulting aspect and volume is not readily accommodated within the space allocation of the electric turbomachine, and that its mounting features be extensive and non-conducive either in terms of minimising cost of materials or efficient use of available volume.

[0054] The present invention provides an electric turbomachine in which the cooling system or cooling circuit for cooling the electric turbomachine, and optionally the electrical machine and power electronics of the electric turbomachine, is integrated within the housing of the electric turbomachine. A cooling system of this nature can be provided by including a series of cavities or conduits that flow through the housing. The cooling system can be arranged such that the coolant fluid within the cooling system flows from the non-drive-end end to the drive-end along an increasing temperature gradient.

[0055] By integrating the cooling system or cooling circuit within the housing of the electric turbomachine the housing itself is cooled and thereby cools any connected or nearby components. Further, providing the cooling system or cooling system within the housing means that the cooling is provided in a location as close to the heat generating or heat sensitive component as possible. For example, a coolant cavity of cooling system may be proximate to the high-speed electrical machine. This is beneficial as the high-speed electrical machine self-generates substantial amounts of heat that would significantly shorten the lifetime of the electrical machine without cooling. Another example is that the cooling system may be proximate to the drive-end bearing helping to prolong the life of the bearing.

[0056] In this way, integrating the cooling system or circuit within the housing reduces the number of parts and associated failure points, efficiently uses previously dead or wasted space within the housing and electric turbomachine.

[0057] The electric turbomachine may optionally comprise a power electronics assembly mounted and provided directly on the housing of the electrical turbomachine, in addition to a cooling system or circuit in accordance with the present invention. Such a combination of features is beneficial for a number of reasons.

[0058] Firstly, the transistors mounted on the power PCBs self-generate heat; if this heat is not removed then its temperature rises leading to a very short component lifetime. By mounting the power PCBs onto the housing of the electrical turbomachine, the cooling circuit within the housing used to cool the electrical machine can additionally cool the power PCBs simultaneously. That is, the cooling circuit can perform double sided cooling. This eliminates the need for a separate power PCB cooling system reduce size, complexity and the number of failure points.

DETAILED DESCRIPTION

[0059] Embodiments of the present invention will now be described by way of example only and with reference to the accompanying drawings, in which:

[0060] FIG. **1** is a cross-section of an electric compressor in accordance with the present claimed invention;

[0061] FIG. **2** is a perspective view of a section of the electric compressor of FIG. **1**;

[0062] FIG. **3** is a second perspective view of a second section of the electric compressor of FIG. **1**, where electric compressor includes the compressor;

[0063] FIG. **4** is a perspective view of the exterior of the electric compressor of FIG. **1**, and in particular the power PCBs, where the power cover has been omitted;

[0064] FIG. **5** is an exploded perspective view of the features shown in FIG. **4**;

[0065] FIG. **6** is the perspective view of the electric compressor of FIG. **4**, where the power cover is included;

[0066] FIG. **7** is a cross-section of the electric compressor of FIG. **1**, where the pathway of the cooling system remains in the half of the machine removed in the cross-section; and

[0067] FIG. **8** is a schematic layout of an electric compressor connected to an internal combustion engine in accordance with the present claimed invention.

[0068] Referring to FIGS. **1** to **3** of the drawings, there is depicted a cross-section, a first perspective sectioned view and a second perspective sectioned view of an electric compressor **10**, in accordance with the present claimed invention. The electric compressor **10** comprises a compressor **20** situated within a turbo compressor **25**. The compressor **20** is connected to a shaft **30** by a threaded fixing **40**. The compressor **20**, turbo compressor **25** and threaded fixing **40** are known in the state of the art and are not within the scope of the invention.

[0069] The shaft **30** protrudes from its fixing with the compressor **20** through the rear-side of the compressor **20** into the housing **50** of the electric compressor **10**. The end of the housing **50** adjacent to the compressor **20** is the drive-end (DE) of the housing **50** and electric compressor **10**, and the opposing end of the housing **50** and electric compressor **10** removed from the compressor **20** is known as the non-drive-end (NDE).

[0070] The wall of the housing at the DE of the housing **50** is known as the drive-end wall **60** and the wall of the housing at the NDE of the housing **50** is known as the non-drive-end wall **80**. The NDE wall **80** and DE wall **60** are connected by a side wall **55** of the housing **50** that extends between them.

[0071] The shaft **30** extends through the DE wall **60** of the housing **50** through the generally cylindrical central cavity **70** inside the housing **50** towards the NDE wall **80**. The DE wall **60** and the NDE wall **80** are separated by the side wall **55** of the housing **50**. The interior side of the side wall **55** is generally cylindrical helping to give the central cavity **70** its generally cylindrical shape. The DE wall **60** and the side wall **55** of the housing **50** are integrally formed from a single piece of aluminium. The NDE wall **80** of the housing **50** is a separate piece that is fixed in position onto the housing **50** by fixings between flanges **56** at the end of the side walls **55** and the NDE wall **80**. In this embodiment, the NDE wall **80** is made aluminium because of its excellent thermal conductance; however, other embodiments are envisaged in which the metals or materials are envisaged. The NDE wall **80** can be removed from the housing **50** to provide access to the central cavity **70**.

[0072] The shaft **30** is mounted on two bearings: the DE bearing **65** and the NDE bearing **85**. The DE bearing **65** is situated within the DE wall **60** and located between the compressor **20** and the rest of the electric turbomachine **10** such as the central cavity **70**. The NDE bearing **85** is located adjacent to the NDE wall **80** in a bearing housing **87**. The bearing housing **87** is attached via an interference fit to the interior side of NDE wall **80**. The bearing housing **87** thermally connects the NDE bearing to the NDE wall.

[0073] The shaft **30** is arranged to be rotated about rotational axis R by a high-speed electrical machine **90** that is located within the central cavity **70** of the housing **50**. The rotational axis R is parallel and coaxial with the longitudinal axis of the shaft **30**. The DE wall **60** and the NDE wall **80** are substantially perpendicular to the rotational axis R of the shaft **30**, and the side wall **55** is substantially parallel to the rotational axis R of the shaft **30**.

[0074] The shaft **30** comprises a rotor portion **100** that is the rotor of the electrical machine **90**. The rotor portion **100** comprises permanent magnets **105** embedded of the surface of the shaft **30**. In alternative embodiments, the permanent magnets **105** are embedded within the interior of the shaft. The rotor portion **100**, and shaft **30**, extend through the stator **110** of the high-speed electrical machine **90**. In this embodiment, the electrical machine **90** is a permanent magnet synchronous motor and the rotor portion **100** and stator **110** are configured in line with the state of the art. The rotor **100** and stator **110** are located approximately centrally along the length of the shaft **30** and approximately centrally between the DE wall **60** and the NDE wall **80** of the housing **50**.

[0075] Surrounding the electrical machine **90** is a jacket **120**. The jacket **120** is generally cylindrical is located around the circumferential walls of the stator **110** such that the jacket **120** is located between the stator **110** and the side wall **55** of the housing **50**. In this way, the jacket **120** acts as an EMI shield for the electrical machine **90**. The jacket **120** also comprises a plurality of cooling channels **130**. The cooling channels **130** are grooves or recesses in the outside surface of the jacket **120**. The cooling channels **130** in combination with the inside surface of the side wall **55** define a helical cooling cavity **140** which are arranged for a flow of coolant fluid around the circumference of the jacket **120** and stator **110**. In this way, the jacket **120** is arranged to cool the electrical machine **90**. The cooling of the electric compressor **10**, and electrical machine **90**, is discussed in depth later.

[0076] The stator **110** comprises windings **150** that extend from either end of the substantially cylindrical stator member **160** into the central cavity **70** of the housing **50**. The windings **150** are configured such that the electrical machine **90** is a three-phase motor as is known in the state of the art. Further embodiments are envisaged where the motor is a six-phase or a nine-phase motor for larger electrical machines.

[0077] The stator member **160** is held in place inside the central cavity **70**, relative to the rotor portion **100**, by the jacket **120**, where the substantially cylindrical stator member **160** sits within and is fixed in place by a friction fit with a shoulder **170** in the interior surface of the jacket **120**.

[0078] The NDE end of windings **150** is electrically connected to a power PCB **180***a* of power electronics assembly **190**, or power electronics by an AC busbar **200***a* and a first electrical connection member **210**. In this embodiment, the power PCB is split up into three separate power PCBs **180***a*, **180***b*, **180***c*, where each power PCBs **180***a*, **180***b*, **180***c* is connected by one of the three separate AC busbars **200***a*, **200***b*, **200***c* to the winding **150** of the stator **110**. The windings **150** are then connected to one another by a star connection.

[0079] Each of power PCBs **180***a*, **180***b*, **180***c* comprises substantially the same circuitry, including transistors **195**, such that this circuitry is triplicated within the power electronics assembly **190**. Other embodiments are envisaged where the power PCB is not split or alternatively split into a number of boards, e.g. two or six. It is preferred that the PCB is split into the number of phases of the electrical machine **90** or motor.

[0080] The electrical connection member **210** extends through the central cavity **70** from the windings **150** towards to NDE wall **80**. From the electrical connection member **210**, the respective AC busbar **200***a*, **200***b*, **200***c* extends up and through the side wall **55** of the housing **50** in a direction substantially perpendicular to the rotational axis R and is electrical connected to the power PCB **180***a*. Each of the AC busbars **200***a*, **200***b*, **200***c* electrically connects the windings **150** at a single point to the AC supplied by its respective power PCB **180***a*, **180***b*, **180***c*. The AC busbar **200***a*, **200***b*, **200***c* is of the braided-type such that it can withstand the heating changes and vibrational forces generated during the lifetime of the machine.

[0081] Referring to FIGS. **4** and **5** drawings, the configuration of the three power PCBs **180***a*, **180***b*, **180***c* is depicted in a perspective view and an exploded perspective view. In this embodiment, as is shown in the drawings each of the power PCBs **180***a*, **180***b*, **180***c* is mounted on the side wall **55** of the housing **50**, and lies in a plane substantially perpendicular with the rotational axis R. That is, the three power PCBs the **180***a*, **180***b*, **180***c* are mounted on three separate flat surfaces **185***a*, **185***b*, **185***c* on the exterior of the side wall **55** of the housing **50**. Each of the three flat surfaces **185***a*, **185***b*, **185***c* lies in a plane substantially parallel with the rotational axis R of the shaft and is substantially planar and rectangular.

[0082] The three flat surfaces **185***a*, **185***b*, **185***c* are configured in a generally square-bottomed U-shape relative to one another, such that one flat surface **185***b* is substantially perpendicular to the other two substantially parallel flat surfaces **185***a*, **185***c*. Or, in other words, the three flat surfaces **185***a*, **185***b*, **185***c* occupy three sides of a square. The three power PCBs **180***a*, **180***b*, **180***c* are each mounted onto one of the flat surfaces **185***a*, **185***b*, **185***c*, such that they are also configured in a generally square-bottomed U-shape relative to each other. Other arrangements of the three flats surface **185***a*, **185***b*, **185***c* and the power PCBs **180***a*, **180***b*, **180***c*, mounted thereon are envisaged, such as a generally triangular arrangement, a pentagonal arrangement or a hexagonal arrangement etc., where the power PCBs are mounted on some or all of the arrangements surfaces.

[0083] All three of the power PCBs **180***a*, **180***b*, **180***c* are supplied with DC power by a DC link busbar **220**. The DC link busbar **220** is connected by two electrical connections **235** to the power PCBs **180***a*, **180***b*, **180***c*. Each of the power PCBs **180***a*, **180***b*, **180***c* acts as an inverter using power electronics as is known in the state of the art. The DC link busbar **220** is generally U-shaped such that it can connect with each of the three power PCBs **180***a*, **180***b*, **180***c* simultaneously.

[0084] Splitting the power PCB into three separate power PCBS **180***a*, **180***b*, **180***c* enables the power PCB to be mounted on the side wall **55** of the housing **50** without extending beyond the circumferential footprint of the DE wall **60**, the turbo compressor **25**. Or, in other words, the power PCB **180***a*, **180***b*, **180***c* does not increase the maximum diameter, or distance from the rotational axis R, of the electric compressor **10**. Instead, this maximum diameter or distance from the rotational axis R is defined by the compressor **25** of the art. In this way, splitting the power PCB **180***a* and incorporating it onto the side of the housing **50** of the electric compressor **10** compacts it. That is, splitting the power PCBs **180***a*, **180***b*, **180***c* substantially reduces the size of the electric compressor **10** as the power PCB **180***a*, **180***b*, **180***c* is not a monolithic PCB and can fit closely and around the components of the electric compressor **10** that are harder to reduce in size. Compacting the electric compressor **10** is on particular importance in vehicle applications due to the limited size in an engine bay of a vehicle. Splitting the power electronics assembly **190** further can help reduce the mass of the electric compressor **10** that is also beneficial in vehicles.

[0085] Referring back to FIGS. **1** to **3**, the DC power supplied to the DC link busbar **220** is supplied by the input busbar **250**. The input busbar **250** is mounted on the exterior side of the NDE wall **80**. The input busbar **250** receives DC electric from a DC source such as a battery in a vehicle. In this embodiment, the electric compressor **10** and its components are configured in this embodiment to work with a 48 V DC supply that is used to power a modern hybrid power train in a vehicle. Other embodiments are envisaged using a DC power supply in the range of 12 to 800+ V.

[0086] Further, the input busbar **250** comprises capacitors **240** that are located on the input busbar **250** and receive power from the DC power supply. The capacitors **240** are located within the NDE wall **80** of the electric compressor **10**. The input busbar **250** and the capacitors **240** are mounted on the NDE wall **80** thus limiting their footprint.

[0087] The control PCB **230** controls the DC power supplied by power PCBs **180***a*, **180***b*, **180***c* to the electrical machine **90** in relation to in relation to the desired speed of electrical machine **90** to achieve the desired boost pressure for the internal combustion engine associated with the electric compressor **10**. The main parameter that the control PCB **230** will request is the speed of the compressor **20** such that the control PCB **230** can control the high-speed electrical engine **90** to provide to boost pressure required. The control PCB **230** may also preferably receive and process inputs from the internal combustion engine such as power demand, power output, efficiency, emissions of the internal combustion engine as well as the temperature and pressure inside the internal combustion engine. In embodiments, where the electric compressor **10** is used in tandem with a turbocharger the control PCB **230** may also receive information regarding the turbocharger speed and boost pressure.

[0088] The control PCB **230** comprises a sensor **260** for detecting of the speed rotation of the shaft **30**, i.e. speed of the electrical machine **90**. The sensor **260** is mounted directly on the control PCB **230** and is located on the rotational axis R of the shaft **30**. The shaft **30** itself extends into a sensor portion **75** of the central cavity **70**, where the sensor portion **75** is substantially cylindrical and extends from the end of the windings **150** towards the NDE wall **80**. The sheath **270** holds the permanent magnet **280** in a position within a sensor portion **75** of the central cavity **70** adjacent to, but not engaging, the rear side of the NDE wall **80**. As such, the permanent magnet **280** mounted onto the shaft **30** proximate to the rear side of the control PCB **230**, and more specifically, the sensor **260**. The speed of the electrical machine **90** is sensed directly by the control PCB **230** by the sensor **260** sensing the rotation of the magnetic fields of the magnet **280**. The sensor **260** and permanent magnet provides an acceleration advantage for the high-speed electrical machine. Embodiments of the electrical turbomachine **10** that do not comprise the sensor **260** and permanent magnet **280** are envisaged. The control PCB **230** is protected by a control cover **290** that completely encapsulates the control PCB **230** in a watertight and airtight manner.

[0089] Referring to FIGS. **5** and **6** of the drawings, there is depicted a power cover **300** for covering and protecting the power PCBs **180***a*, **180***b*, **180***c*. The cover **300** is arranged to be fixed by screws **305** onto a rim **310** of the housing **50**. The cover **300** is generally U-shaped and is integrally formed from a single piece. When the cover **300** is attached to the rim **310** of the housing **50**, a rubber seal **320** is sandwiched between the cover **300** and the rim **310**. The rubber seal **320** is compressed between the cover and the rim **310** to give a watertight seal. Using a single cover, the power cover **300**, reduces the number of egress points and point points of failure of fluids.

[0090] Accordingly, due to the control cover **290** and power cover **300**, the electric compressor **10** can be used in vehicles as the power electronics assembly **190** is sufficiently protected from water and cleaning products used to clean the engine bay of a vehicle.

[0091] The implementation as described of the power electronics assembly **190** as described above produces a design implementation that does not need a separate installation location, separate connections and sealing requirements and thereby avoids increasing in the number of failure modes. Further, the implementation of the power electronics assembly **190** distributes the power electronics assemblies around the machine enables the power electronics assembly **190** to stay closer to the outline of the machine and, essentially, reducing its size such that it is kept within the overall confines of circumferential footprint and space allocation of the electrical turbomachine.

[0092] Referring to FIG. **7**, the cooling system **330** of the electric compressor **10** in accordance with the present invention is depicted. FIG. **7** depicts a cross-section where half of the electric compressor **10** has been removed. In the half that has been "cut-away" in FIG. **7**, the cooling system **330** has been left to illustrate cooling system **330**.

[0093] A single cooling system **330** is used to cool all of the components of the electric compressor **10**. The cooling system **330** comprises a continuous cooling circuit around the interior of housing **50** of the electric compressor **10**. The cooling system **330** is design for a coolant fluid, such as water, glycol or another suitable coolant, to be pumped, by a pump (not shown), around the interior of the electric compressor **10**. The cooling system **330** comprises a plurality of individual cooling cavities, as described herein, connected directly or by a number of cooling conduits to form a complete cooling system **330** for the entire electric compressor **10**. Each of the cooling cavities is surrounded by a thermally conductive material to assist in the transfer of heat form the electric compressor **10** to the coolant fluid. In this embodiment, aluminium is preferred due to its excellent the thermally conductivity, immunity to rust, resistance to corrosion and strong mechanical properties.

[0094] The coolant fluid enters the cooling system **330** at the coolant inlet **340** which is located on the side wall **55** of the housing **50** and proximate the NDE wall **80** and NDE of the electric compressor **10**. The positioning of the coolant inlet **340** is flexible but it is preferred from it to be closer to the NDE of the electric compressor.

[0095] From the coolant inlet **340**, the coolant fluid can flow through to a capacitor coolant cavity **350**. The capacitor coolant cavity **350** is formed between the flanges **56** of the housing **50** and the NDE wall **80**, and extends substantially along the end of the capacitors **240** removed from the control PCB **230**.

[0096] From the capacitor coolant cavity **350** the coolant can flow into the NDE coolant cavity **360**. The NDE coolant cavity **360** is a torus-shaped, or toroid-shaped, cavity in the NDE wall **80** that encircles the sensor portion **75** of the central cavity **70**. It is important to keep the permanent magnet **280** for the sensor **260** cool, such that the magnetism of the permanent magnet **280** is not degaussed. The NDE coolant cavity **360** not only cools the sensor cavity **75** but also cools the interior and exterior sides of the NDE wall **80**. The NDE coolant cavity **360** aids in cooling both the central cavity **70** and the components housed therein, including the sensor portion **75** of the cavity, but also the control board **230** mounted on the exterior surface of the NDE wall **80**. The NDE coolant cavity **360** therefore performs triple-sided cooling.

[0097] Furthermore, the NDE coolant cavity **360** is thermally linked with the bearing housing **87** such that it can removed heat conducted along the shaft which heats the NDE bearing **85** and self-heating of the NDE bearing **85**. These heat flows act to increase the operating temperature of this bearing **85**, which would lead to a markedly reduced life if it were not cooled by the NDE coolant cavity **360**.

[0098] The NDE coolant cavity **360** does not extend the full height or width of the NDE wall **80** or control board **230**. A control PCB coolant cavity **370** is provided to cool the part of the control PCB **230** not sufficiently cooled by the capacitor coolant cavity **350** or the NDE coolant cavity **360**. The control PCB coolant cavity **370** is substantially plate-like or disc-like and is a cavity within the NDE wall **80** and is supplied with coolant fluid from the NDE coolant cavity **360**.

[0099] The capacitor coolant cavity **350**, the NDE coolant cavity **360** and the control PCB cooling cavity **370** are the NDE wall coolant portion **380** of the cooling system **330** and each of the cavities is fluidly connected to allow coolant fluid to circulate throughout them via a continuous pathway or circuit.

[0100] The NDE wall coolant portion **380** is fluidly connected to the central coolant portion **390** by a first cooling conduit **400**. The first cooling conduit **400** supplies coolant fluid to the central coolant portion **390** and a helix coolant cavity **410**. The helix coolant cavity **410** is a continuous helix that wraps around the electrical machine **90** from the NDE wall **80** towards the DE wall **60**. The helix coolant cavity **410** is formed from the coolant channels **130** in the jacket **120** engaging with the side wall **55** of the housing **50**. That is, the jacket **120** comprises a helical coolant channel **130** in its exterior surface that is sealed by engaging the side wall **55**. The majority of the exterior surface of the jacket **120** is the coolant channel **130**. The cross-section of a portion of the helix coolant cavity **410** is generally rectangular. The longer edges of the rectangular cross-section are parallel to the rotational axis R. In this embodiment, the helix of the coolant channel **130**, and the helix coolant cavity **410**, has seven turns. The number of turns and the helical geometry of the helix coolant cavity **410** can be modified according to the requirements of the cooling system **330**. For example, the number of turns could be increased to increase heat transfer to the coolant with the drawback of the higher inlet pressure due to increased pressure drop across the fluid. In this embodiment, seven turns was found by the applicant to be a comprise which provided adequate cooling while simultaneously not increasing the pressure beyond that of the rating of the pump typically used in the desired application. This is because the coolant fluid in this embodiment will be provided by the pump of the internal combustion engine's coolant system. Other embodiments are envisaged in that the coolant cavity **410** is not a helix but rather interconnected parallel channels.

[0101] Coolant fluid entering the helix coolant cavity **410** will circle the electrical machine **90** seven times before exiting the helix coolant cavity **410** and entering the DE cooling portion **420** by a second conduit **430**. The helix coolant cavity **410** has a double-sided cooling activity as it cools both the electrical machine **90** (i.e. central cavity **70**, rotor **90**, stator **110** and windings **150**) and the power PCBs **180***a*, **180***b*, **180***c* via cooling the jacket **120** and side wall **55**, respectively.

[0102] The turn of the helix coolant cavity **410** proximate the DE wall **60** is fluidly connected by a second cooling conduit **430** to the DE coolant cavity **440**. The DE coolant cavity **430** is a torus-shaped, or toroid-shaped, cavity within the DE wall **60** that encircles the DE bearing **65** and the location on the DE wall **60** which the shaft **30** protrudes through the DE wall **60** to connect to the compressor **20**. The DE coolant cavity **430** is substantially larger in volume than the similarly shaped NDE coolant cavity **360**, reflecting the fact that, in use, the DE of the electric compressor **10** will be substantially hotter than the NDE of the electric compressor **10** in use. This is because of the DE proximity to the hot fluids (i.e. compressed engine intake air) onto which the turbo compressor **25** and compressor **20** have performed work. The DE coolant cavity **440** performs triple sided cooling of the central cavity **70** and DE bearing **65**. Integrating the DE bearing **65** within the DE wall **60** enables the DE bearing **65** to be cooled by the DE coolant cavity **440**. Heat from the compressor **25** is conducted into the electric compressor **10** through the housing **55** and heats the DE bearing **65** and the DE bearing **65** self-generates heat internally. These heat flows act to increase the operating temperature of the DE bearing **65**, which would lead to a markedly reduced lifespan if not cooled. This problem is addressed by the DE coolant cavity **430** that not only cools heat from the compressor **20** but also the self-generated heat from the DE bearing **65**.

[0103] The coolant fluid leaves the DE coolant cavity **440** via an outlet **450**. In use, the outlet **450** is connected by piping to a radiator such that the coolant fluid can be cooled before circulating back into the cooling system **330** via the inlet **340**. The cooling system **330** flows from the NDE cooling portion **380** to helix coolant cavity **410** to DE coolant cavity **440** the DE end of the electric compressor **10** is hotter than the NDE. By pumping the coolant fluid in this direction, i.e. along increasing temperature gradient, the cooling system **330** ensures that each part of the electric compressor **10** is sufficiently cooled.

[0104] In the prior art, the control PCB **230** and the power PCBs **180***a*, **180***b*, **180***c* are typically cooled by one or more cooling systems and the electrical machine **90** by another cooling system. This significantly increases the size of the electric compressor **10**. The electric compressor **10** and cooling system **330** of the present invention has the advantage of being more compact and have less components as a single cooling system **330** or cooling circuit can cool every part of the electric turbomachine **10**. This is particular advantageous in vehicle applications as it reduces the size of the electric compressor **10** such that is occupies less space in the engine bay while also reducing the mass of the overall system.

[0105] Referring to FIG. **8** of the drawings, there is shown a schematic diagram showing how an electric compressor **10** could be connected in relation to an internal combustion engine **11**. The electric compressor **10** is in accordance with the present invention and comprises power electronics **190** that supplies a current to a high-speed electrical machine **90**. The high-speed electrical machine **90** is arranged to convert the electric current suppled to it by the power electronics **190** to rotation of the shaft **30** and the compressor **20** connected by the end of the shaft **30**. Rotation of the compressor **20** by the high-speed electrical machine **90** draws in air and compresses the air, boosting the pressure of the air. Typically, the electric compressor **10** is located downstream of pressure boosting system, such as a turbocharger, and the electric compressor **10** further boosts the pressure of the air from the turbocharger. This is particularly useful for providing a rapid increase in boost pressure during the start-up or warm-up of a system or during transient or high-load events. Alternatively, the electric compressor **10** can draw and boost the pressure of air drawn directly form the environment. The pressure-boosted air leaves the compressor **20** by the inlet conduit **12** and travels towards the internal combustion engine **11**. Along the pathway of the inlet conduit **12** is located a radiator **13** which is arranged to cool the pressure-boosted air in the inlet conduit **12**, prior to the pressure-boosted air entering the internal combustion engine **11**. The amount of boost pressure generated by the electric compressor **10** in the pressure-boosted air is controlled by the speed of rotation of the high-speed electrical machine **90**, whereby the rotational speed of the high-speed electrical machine **90** is controlled from inputs from the power electronics **190**. The power electronics **190** can control the boost pressure in response to a number of sensors or readings, for example, this will typically be a request from the engine control unit that will request a set speed. However, other parameters could be measured such as the power, emissions or efficiency of the internal combustion engine **11** and the power electronics assembly **190** could respond accordingly.

[0106] The above description refers exclusively to an electric compressor **10**. Other embodiments, including other electric turbomachines are envisaged. For example, a turbocharger or turbogenerator where the power electronics are similarly mounted directly onto the housing of the turbocharger or turbogenerator to reduce the footprint and packaging size. Additionally, an electric turbomachine comprising a single cooling system integrated into the housing of the turbocharger or turbogenerator to provide cooling for its electrical machine and its power electronics assembly is within the scope of the present invention.

1. An electric turbomachine for use with an internal combustion engine, a turbocharger or a fuel cell e-compressor, said electric turbomachine comprising:

a compressor that is arranged to compress fluid within a turbo compressor when it is rotationally driven about a rotational axis (R) by a shaft, said shaft being rotational supported by a drive-end bearing and a non-drive-end bearing, and

a high-speed electrical machine located within a housing that is arranged to rotationally drive the shaft about the rotational axis (R);

said housing comprising a drive-end wall that the shafts extends through to rotationally drive the compressor, a non-drive-end wall at the opposing end of the electric turbomachine to the compressor, and a side wall that extends between the drive-end wall and the non-drive-end wall, and

wherein the electric turbomachine comprises a cooling system, for receiving a flow of a coolant fluid to cool the electric turbomachine, that is integrated within the housing of the electric turbomachine.

2. The electric turbomachine of claim **1**, wherein the cooling system comprises a drive-end coolant cavity located within the drive-end wall for receiving a flow of coolant fluid to cool the electric turbomachine.

3. The electric turbomachine of claim **2**, wherein the drive-end coolant cavity encircles the shaft as it extends through the drive-end wall.

4. The electric turbomachine of claim **2**, wherein the drive-end coolant cavity is arranged to cool the drive-end bearing.

5. The electric turbomachine of claim **4**, wherein the drive-end coolant cavity encircles the drive-end bearing.

6. The electric turbomachine of claim **1**, wherein the cooling system comprises a non-drive-end coolant cavity located within the non-drive-end wall for receiving a flow of fluid coolant to cool the electric turbomachine.

7. The electric turbomachine of claim **6**, wherein the non-drive-end coolant cavity encircles the non-drive end of the shaft.

8. The electric turbomachine of claim **6**, wherein non-drive-end coolant cavity encircles the non-drive end bearing.

9. The electric turbomachine of claim **6**, wherein the non-drive-end coolant cavity is arranged to cool power electronics that are mounted on an exterior surface of the non-drive-end wall.

10. The electrical turbomachine of claim **9**, wherein non-drive-end coolant cavity comprises one or more plate-like or disc-like portions that are arranged to cool the power electronics mounted on the exterior surface of the non-drive- end wall.

11. The electric turbomachine of claim **9**, wherein the non-drive-end coolant cavity is arranged to cool a control printed circuit board that is mounted on the exterior surface of the non-drive-end wall.

12. The electric turbomachine of claim **9**, wherein the non-drive-end coolant cavity is arranged to cool capacitors.

13. The electric turbomachine of claim **1**, wherein the cooling system comprises a side wall coolant cavity located within the side wall for receiving a flow of coolant fluid to cool the electric turbomachine.

14. The electric turbomachine of claim **13**, wherein the side wall coolant cavity is arranged to cool the electrical machine.

15. The electric turbomachine of claim **14**, wherein the side wall coolant cavity is arranged to cool power electronics that are mounted on an exterior surface of the side wall.

16. The electric turbomachine of claim **15**, wherein the side wall coolant cavity is arranged to cool a power printed circuit board that is mounted on the exterior surface of the side wall.

17. The electric turbomachine of claim **16**, wherein the side wall coolant cavity is arranged to cool a plurality of power PCBs that are mounted on one or more exterior surfaces of the side wall.

18. The electric turbomachine of claim **14**, wherein the majority of the side wall coolant cavity is formed between an interior surface of the side wall and one or more channels in the surface of a jacket that supports the electrical machine.

19. The electric turbomachine of claim **14**, wherein the majority of the side wall coolant cavity is formed within the side wall of the housing.

20. The electric turbomachine of claim **1**, wherein the cooling system comprises a drive-end coolant cavity located within the drive-end wall for receiving a flow of coolant fluid to cool the electric turbomachine, a non-drive-end cavity located within the non-drive-end wall for receiving a flow of fluid coolant to cool the electric turbomachine, and a side wall coolant cavity located within the side wall for receiving a flow of coolant fluid to cool the electric turbomachine.

21. The electric turbomachine of claim **20**, wherein the drive-end coolant cavity, the non-drive-end coolant cavity and the side wall coolant cavity are fluidly connected to one another to form a continuous pathway inside the housing for receiving a flow of coolant fluid to cool the electric turbomachine.

22. The electric turbomachine of claim **21**, wherein the fluid connections between the drive-end coolant cavity, non-drive-end coolant cavity and the side wall coolant cavity are integrated within the drive-end wall, non-drive-end wall and the side wall.

23. The electric turbomachine of claim **22**, wherein the drive-end coolant cavity is fluidly connected to the side wall coolant cavity, and the side wall coolant cavity is fluidly connected to the non-drive-end coolant cavity.

24. The electric turbomachine of claim **23**, wherein the cooling system is arranged such that, in use, coolant fluid flows into the cooling system via an inlet into the non-drive-end wall cavity and coolant fluid flows out of the cooling system via an outlet from the drive-end wall cavity.

25. The electric turbomachine of claim **1**, wherein the cooling system is the only system used to actively cool the electric turbomachine.

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