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(54) THERMOMAGNETIC COOLING USING MAGNETORHEOLOGICAL FLUID

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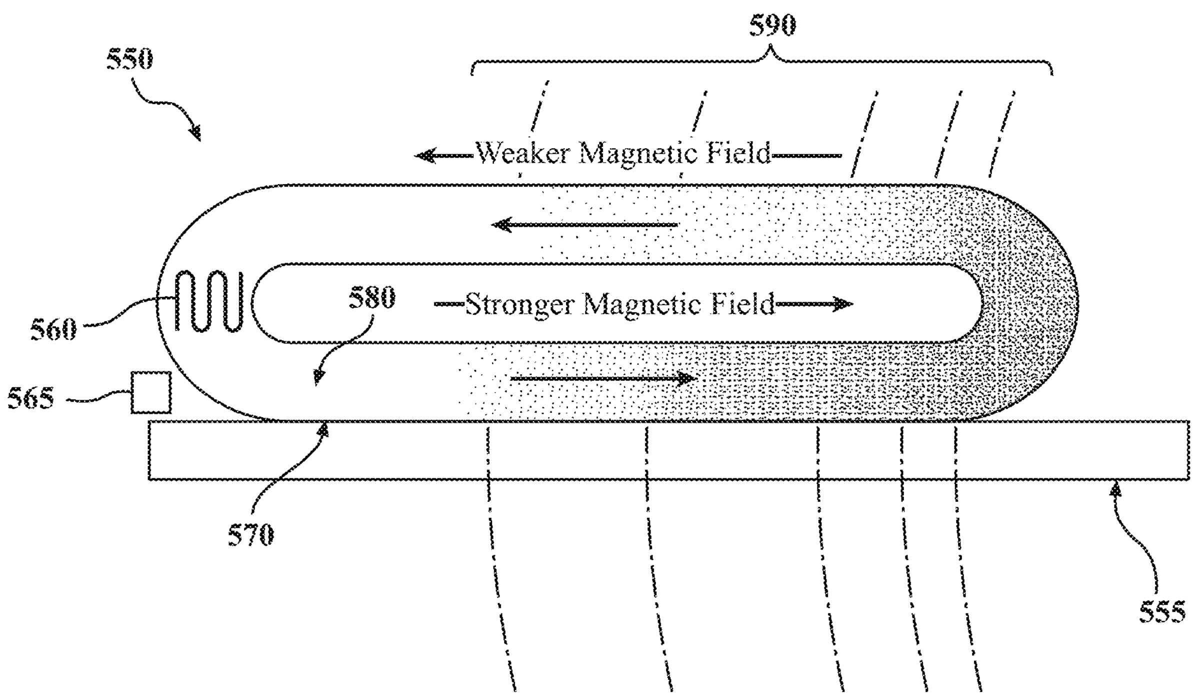
(57) **ABSTRACT**

Systems and methods described herein relate to implementing magnetorheological fluid-based cooling and electromagnetic interference shielding strategies. In one embodiment, a method includes storing magnetorheological fluid in a loop, utilizing a heat exchanger coupled to the loop to cool the magnetorheological fluid, utilizing a swing check valve within the loop to constrain flow of the magnetorheological fluid, and utilizing a structure forming a segment of the loop where the magnetorheological fluid provides cooling, electromagnetic interference shielding, or both to a vehicular component.



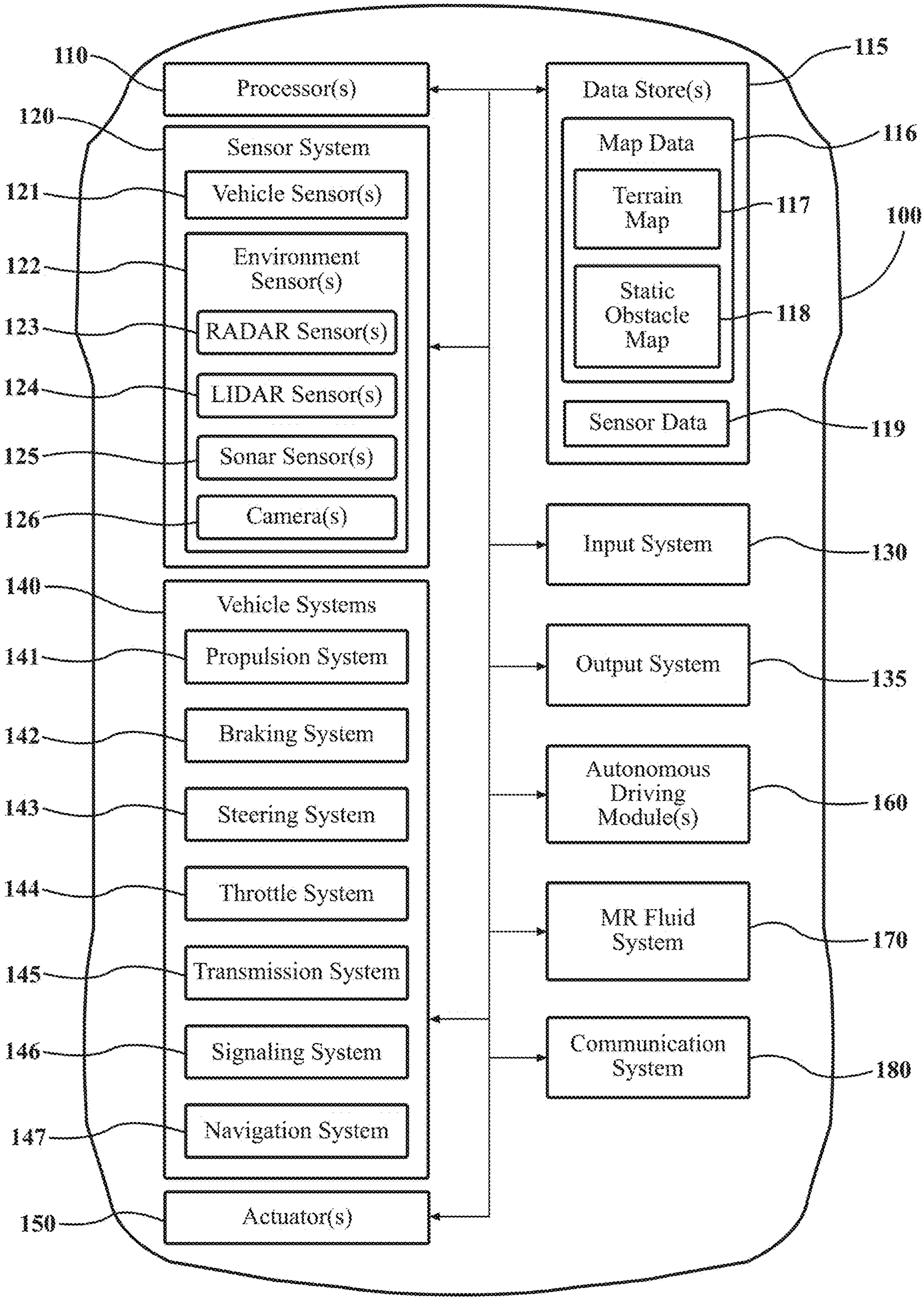

110
Processor(s)
115
Data Store(s)
120
Sensor System
116
Map Data
121
Vehicle Sensor(s)
Terrain Map
117
100
122
Environment Sensor(s)
Static Obstacle Map
118
123
RADAR Sensor(s)
124
LIDAR Sensor(s)
Sensor Data
119
125
Sonar Sensor(s)
126
Camera(s)
Input System
130
140
Vehicle Systems
141
Propulsion System
Output System
135
142
Braking System
143
Steering System
Autonomous Driving Module(s)
160
144
Throttle System
MR Fluid System
170
145
Transmission System
146
Signaling System
Communication System
180
147
Navigation System
150
Actuator(s)

FIG. 1

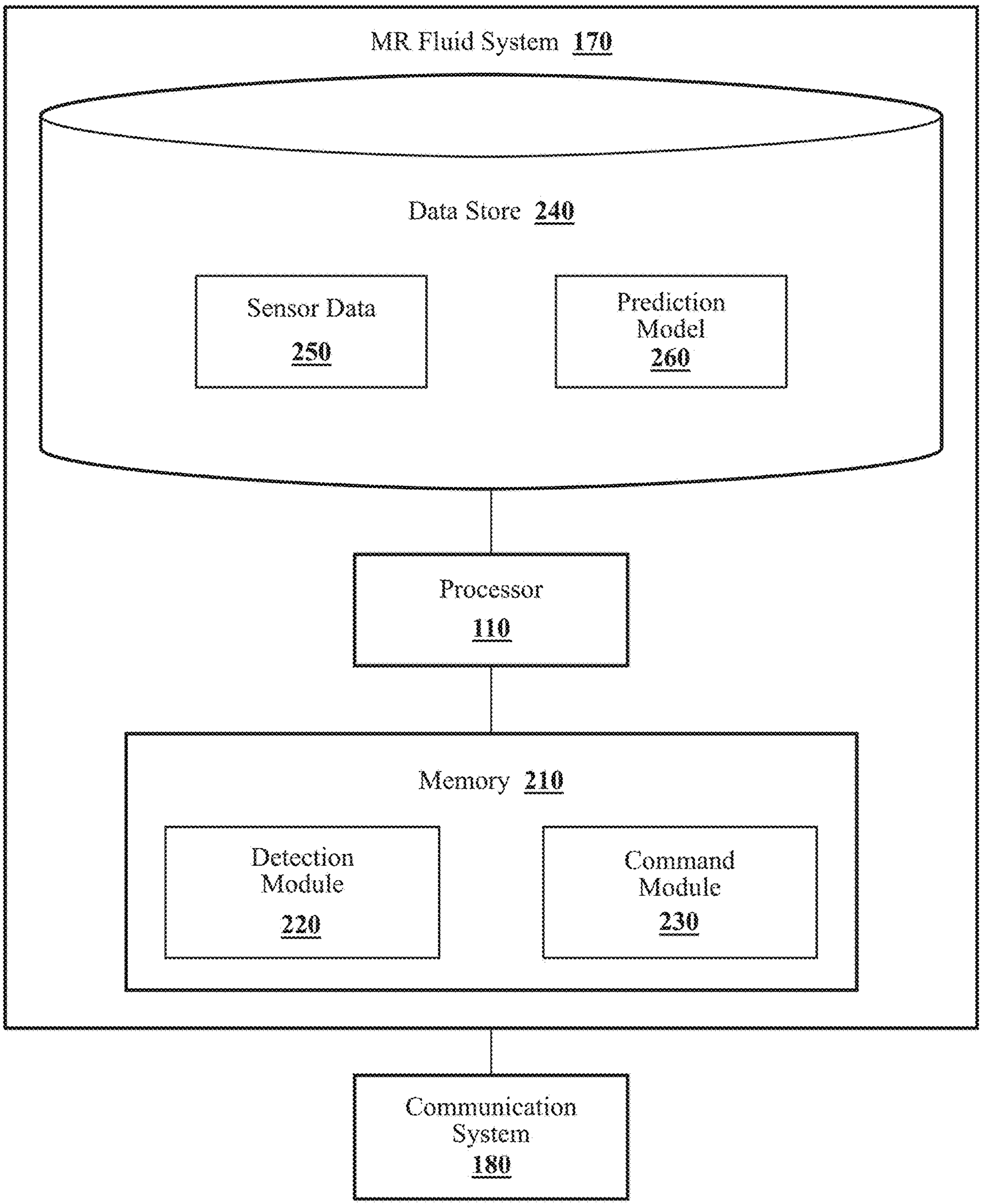

MR Fluid System 170
Data Store 240
Sensor Data 250
Prediction Model 260
Processor 110
Memory 210
Detection Module 220
Command Module 230
Communication System 180

FIG. 2

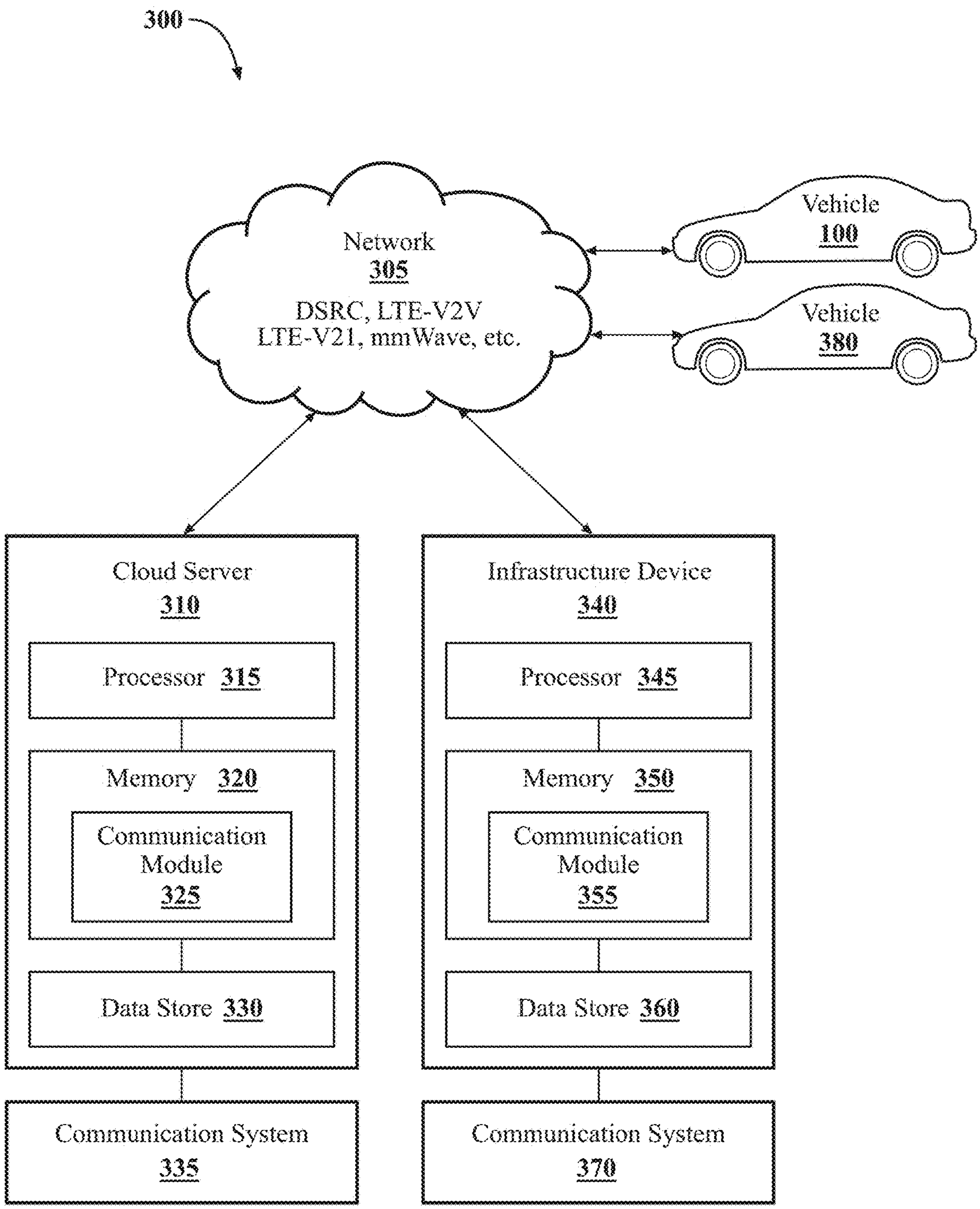

300
Network
305
DSRC, LTE-V2V
LTE-V21, mmWave, etc.
Vehicle
100
Vehicle
380
Cloud Server
310
Processor 315
Memory 320
Communication
Module
325
Data Store 330
Communication System
335
Infrastructure Device
340
Processor 345
Memory 350
Communication
Module
355
Data Store 360
Communication System
370

FIG. 3

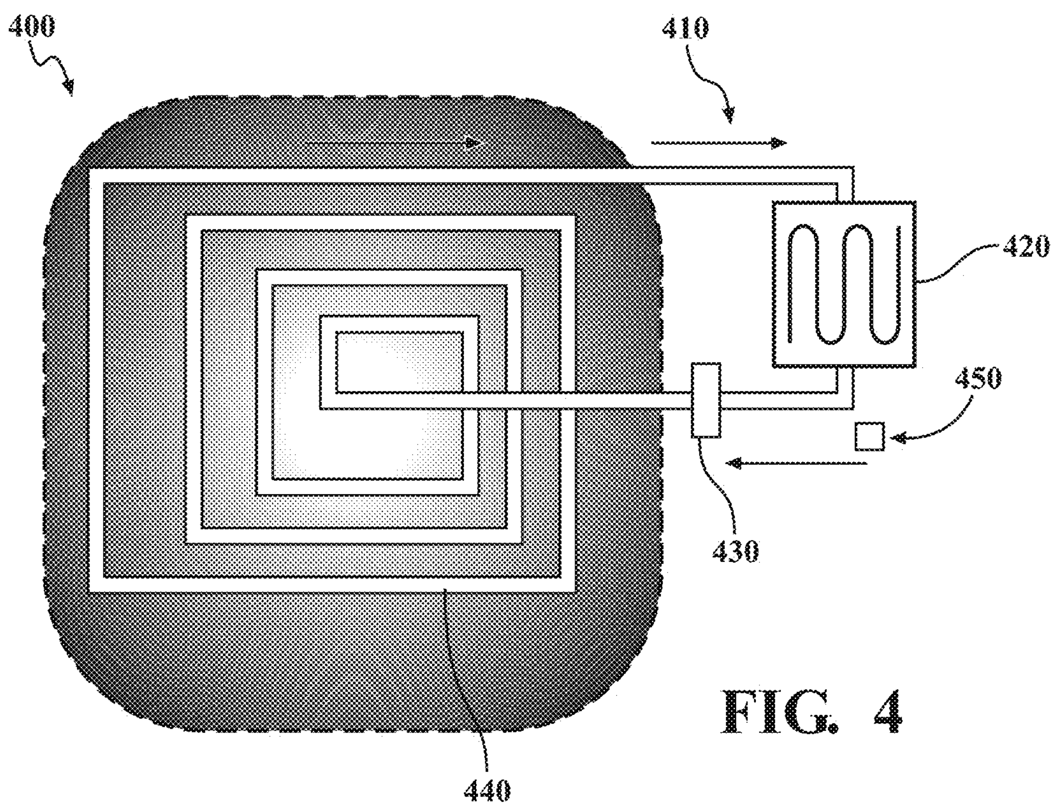


FIG. 4

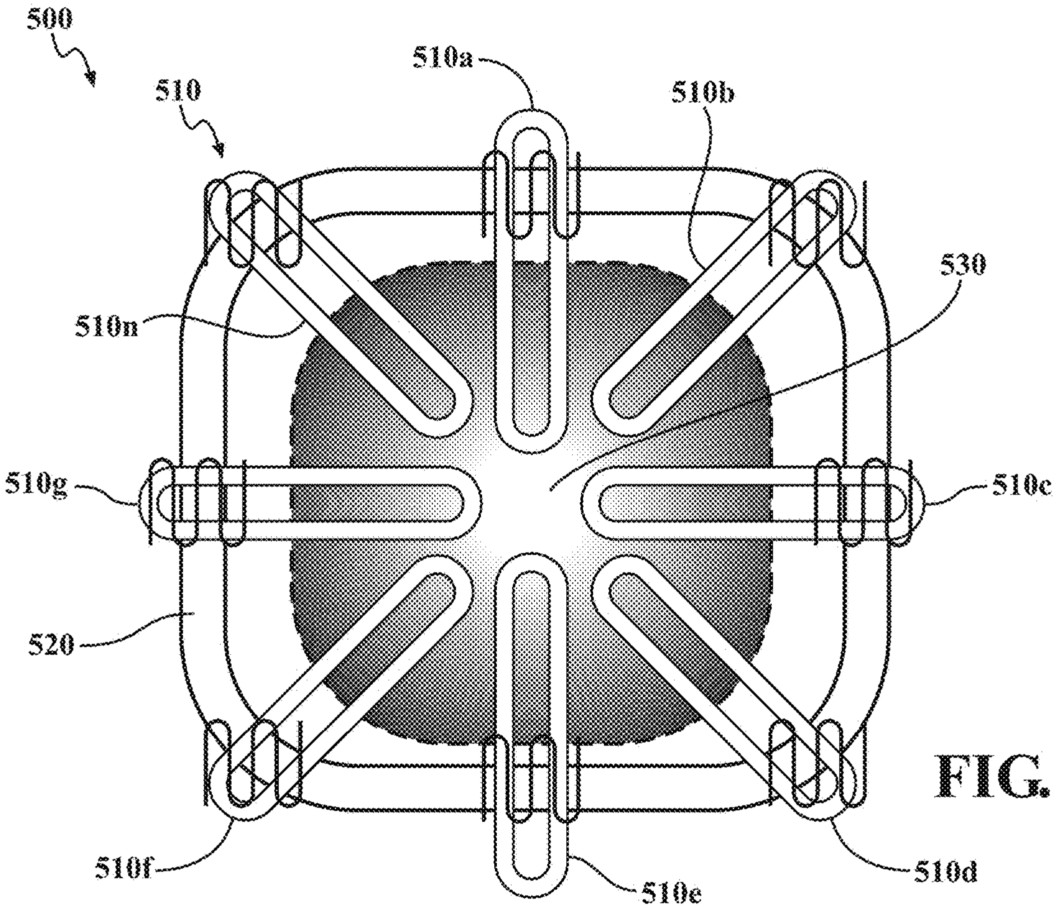

500
510
510a
510b
530
510n
510g
510c
520
510f
510e
510d

FIG. 5A

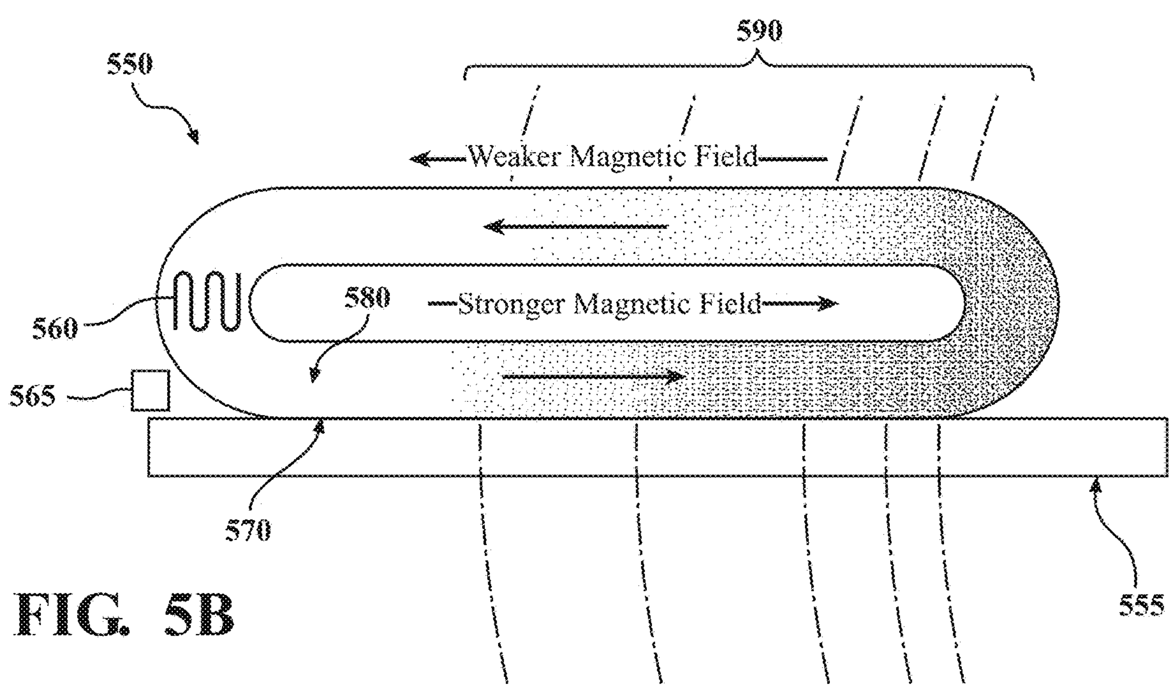

590
550
Weaker Magnetic Field
Stronger Magnetic Field
580
560
565
570
555

FIG. 5B

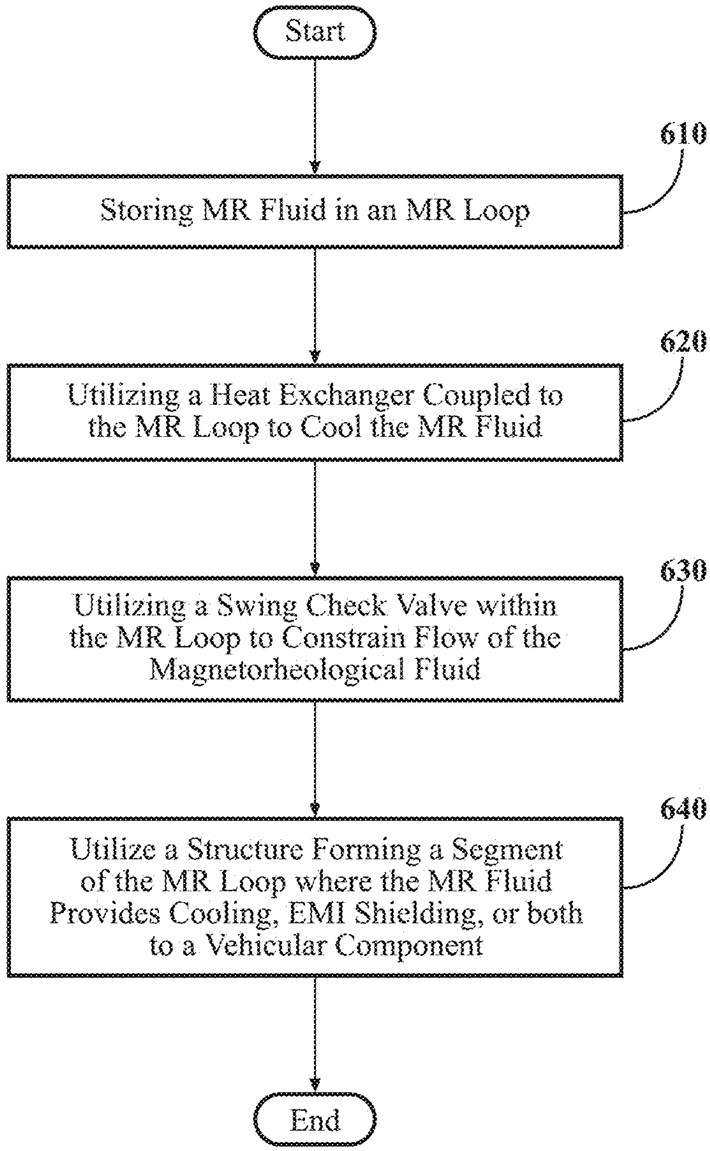

Start
610
Storing MR Fluid in an MR Loop
620
Utilizing a Heat Exchanger Coupled to the MR Loop to Cool the MR Fluid
630
Utilizing a Swing Check Valve within the MR Loop to Constrain Flow of the Magnetorheological Fluid
640
Utilize a Structure Forming a Segment of the MR Loop where the MR Fluid Provides Cooling, EMI Shielding, or both to a Vehicular Component
End

FIG. 6

THERMOMAGNETIC COOLING USING MAGNETORHEOLOGICAL FLUID

CROSS REFERENCE TO RELATED APPLICATION

[0001] This invention is related to U.S. patent application Ser. No. 18/441,054, filed same day as the present application, titled "Magnetorheological Fluid System for Cooling and Electromagnetic Interference Shielding," the disclosures of which are incorporated herein by reference and made a part hereof.

TECHNICAL FIELD

[0002] The subject matter described herein relates, in general, to strategies for cooling and electromagnetic interference shielding, and, more particularly, to using a magnetorheological fluid system to provide such cooling and electromagnetic interference shielding.

BACKGROUND

[0003] Wireless charging generates heat and electromagnetic interference. One approach to managing heat with respect to wireless charging is limit power transference to keep temperatures low. With respect to electromagnetic interference, vehicles may use metal shielding to block signals or ferrite bars whose magnetic flux alters the radiation of signals.

SUMMARY

[0004] In one embodiment, a system is disclosed. The system includes a loop containing magnetorheological fluid, a heat exchanger coupled to the loop to cool the magnetorheological fluid, a swing check valve within the loop to constrain flow of the magnetorheological fluid, and a structure forming a segment of the loop where the magnetorheological fluid provides cooling to a vehicular component.

[0005] In one embodiment, another system is disclosed. The system includes a set of loops containing magnetorheological fluid, a heat exchanger coupled to the set of loops to cool the magnetorheological fluid, and a structure forming a corresponding segment of each loop where the magnetorheological fluid provides cooling to a vehicular component.

[0006] In one embodiment, a method for implementing magnetorheological fluid-based cooling or shielding strategies is disclosed. In one embodiment, the method includes storing magnetorheological fluid in a loop, utilizing a heat exchanger coupled to the loop to cool the magnetorheological fluid, utilizing a swing check valve within the loop to constrain flow of the magnetorheological fluid, and utilizing a structure forming a segment of the loop where the magnetorheological fluid provides cooling to a vehicular component.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate various systems, methods, and other embodiments of the disclosure. It will be appreciated that the illustrated element boundaries (e.g., boxes, groups of boxes, or other shapes) in the figures represent one embodiment of the boundaries. In some embodiments, one element may be designed as multiple elements or multiple elements may be designed as one element. In some embodiments, an element shown as an internal component of another element may be implemented as an external component and vice versa. Furthermore, elements may not be drawn to scale.

[0008] FIG. **1** illustrates one embodiment of a vehicle within which systems and methods disclosed herein may be implemented.

[0009] FIG. **2** illustrates one embodiment of an MR fluid system that is associated with implementing magnetorheological fluid-based cooling or shielding strategies.

[0010] FIG. **3** illustrates one embodiment of a cloud computing environment within which the systems and methods described herein may operate.

[0011] FIG. **4** illustrates one example of an MR fluid system for cooling or EMI shielding.

[0012] FIG. **5**A illustrates a further example of an MR fluid system for cooling or EMI shielding.

[0013] FIG. **5**B illustrates a different perspective of the further example of an MR fluid system for cooling or EMI shielding.

[0014] FIG. **6** illustrates one example of a method for cooling and electromagnetic interference (EMI) shielding.

DETAILED DESCRIPTION

[0015] Systems, methods, and other embodiments associated with a magnetorheological (MR) fluid system to provide cooling and electromagnetic interference (EMI) shielding are described herein. MR fluids are a class of smart materials characterized by fast, tunable and reversible changes of their rheological properties under application of magnetic fields. MR fluids consist of dispersions of micron sized particles of magnetizable materials dispersed in a liquid. Application of magnetic fields results in the magnetization of the dispersed particles, which consequently experience attractive forces, giving rise to the formation of particle structures that oppose to the flow.

[0016] Rather than using ferrite for EMI shielding, MR fluid loops may be used to provide EMI shielding. In addition, the MR fluid loops may also be used to provide cooling, such as for transmission coils that may run hot while charging. Movement of the MR fluid within an MR fluid loop may be achieved by use of magnetic attraction of the MR fluid, which may be enhanced by using a swing check valve. Accordingly, passive MR fluid-based systems are described herein that may provide cooling or EMI shielding to vehicle components.

[0017] Referring to FIG. **1**, an example of a vehicle **100** is illustrated. As used herein, a "vehicle" is any form of motorized transport. In one or more implementations, vehicle **100** is an automobile. While arrangements will be described herein with respect to automobiles, it will be understood that embodiments are not limited to automobiles. In some implementations, vehicle **100** may be any robotic device or form of motorized transport that, for example, includes sensors to perceive aspects of the surrounding environment, and thus benefits from the functionality discussed herein associated with MR fluid-based cooling or shielding strategies. As a further note, this disclosure generally discusses vehicle **100** as traveling on a roadway with surrounding vehicles, which are intended to be construed in a similar manner as vehicle **100** itself. That is, the surrounding vehicles may include any vehicle that may be encountered on a roadway by vehicle **100**.

[0018] Vehicle **100** also includes various elements. It will be understood that in various embodiments it may not be necessary for vehicle **100** to have all of the elements shown in FIG. **1**. Vehicle **100** may have any combination of the various elements shown in FIG. **1**. Further, vehicle **100** may have additional elements to those shown in FIG. **1**. In some arrangements, vehicle **100** may be implemented without one or more of the elements shown in FIG. **1**. While the various elements are shown as being located within vehicle **100** in FIG. **1**, it will be understood that one or more of these elements may be located external to vehicle **100**. Further, the elements shown may be physically separated by large distances. For example, as discussed, one or more components of the disclosed system may be implemented within a vehicle while further components of the system are implemented within a cloud-computing environment or other system that is remote from vehicle **100**.

[0019] Some of the possible elements of vehicle **100** are shown in FIG. **1** and will be described along with subsequent figures. However, a description of many of the elements in FIG. **1** will be provided after the discussion of FIGS. **2-6** for purposes of brevity of this description. Additionally, it will be appreciated that for simplicity and clarity of illustration, where appropriate, reference numerals have been repeated among the different figures to indicate corresponding or analogous elements. In addition, the discussion outlines numerous specific details to provide a thorough understanding of the embodiments described herein. Those of skill in the art, however, will understand that the embodiments described herein may be practiced using various combinations of these elements. In either case, vehicle **100** includes a MR fluid system **170** that is implemented to perform methods and other functions as disclosed herein relating to implementing cooling or EMI shielding strategies. As will be discussed in greater detail subsequently, MR fluid system **170**, in various embodiments, is implemented partially within vehicle **100** and as a cloud-based service. For example, in one approach, functionality associated with at least one module of MR fluid system **170** is implemented within vehicle **100** while further functionality is implemented within a cloud-based computing system.

[0020] With reference to FIG. **2**, one embodiment of MR fluid system **170** of FIG. **1** is further illustrated. MR fluid system **170** is shown as including processor(s) **110** from vehicle **100** of FIG. **1**. Accordingly, processor(s) **110** may be a part of MR fluid system **170**, MR fluid system **170** may include a separate processor from processor **110** (*s*) of vehicle **100**, or MR fluid system **170** may access processor **110** (*s*) through a data bus or another communication path. In one embodiment, MR fluid system **170** includes memory **210**, which stores detection module **220** and command module **230**. Memory **210** is a random-access memory (RAM), read-only memory (ROM), a hard-disk drive, a flash memory, or other suitable memory for storing detection module **220** and command module **230**. Detection module **220** and command module **230** are, for example, computer-readable instructions that when executed by processor(s) **110** cause processor(s) **110** to perform the various functions disclosed herein.

[0021] MR fluid system **170** as illustrated in FIG. **2** is generally an abstracted form of MR fluid system **170** as may be implemented between vehicle **100** and a cloud-computing environment. Accordingly, MR fluid system **170** may be embodied at least in part within a cloud-computing environment to perform the methods described herein.

[0022] With reference to FIG. **2**, detection module **220** generally includes instructions that function to control processor(s) **110** to receive data inputs from one or more sensors of vehicle **100**. The inputs are, in one embodiment, observations of one or more objects in an environment proximate to vehicle **100**, other aspects about the surroundings, or both. As provided for herein, detection module **220**, in one embodiment, acquires sensor data **250** that includes at least camera images. In further arrangements, detection module **220** acquires sensor data **250** from further sensors such as radar **123**, LiDAR **124**, and other sensors as may be suitable for identifying vehicles, locations of the vehicles, lane markers, crosswalks, traffic signs, vehicle parking areas, road surface types, curbs, vehicle barriers, and so on. In one embodiment, detection module **220** may also acquire sensor data **250** from one or more sensors that allow for implementing MR fluid-based cooling or shielding strategies.

[0023] Accordingly, detection module **220**, in one embodiment, controls the respective sensors to provide sensor data **250**. Additionally, while detection module **220** is discussed as controlling the various sensors to provide sensor data **250**, in one or more embodiments, detection module **220** may employ other techniques to acquire sensor data **250** that are either active or passive. For example, detection module **220** may passively sniff sensor data **250** from a stream of electronic information provided by the various sensors to further components within vehicle **100**. Moreover, detection module **220** may undertake various approaches to fuse data from multiple sensors when providing sensor data **250**, from sensor data acquired over a wireless communication link (e.g., v2v) from one or more of the surrounding vehicles, or from a combination thereof. Thus, sensor data **250**, in one embodiment, represents a combination of perceptions acquired from multiple sensors.

[0024] In addition to locations of surrounding vehicles, sensor data **250** may also include, for example, odometry information, GPS data, or other location data. Moreover, detection module **220**, in one embodiment, controls the sensors to acquire sensor data about an area that encompasses 360 degrees about vehicle **100**, which may then be stored in sensor data **250**. In some embodiments, such area sensor data may be used to provide a comprehensive assessment of the surrounding environment around vehicle **100**. Of course, in alternative embodiments, detection module **220** may acquire the sensor data about a forward direction alone when, for example, vehicle **100** is not equipped with further sensors to include additional regions about the vehicle or the additional regions are not scanned due to other reasons (e.g., unnecessary due to known current conditions).

[0025] Moreover, in one embodiment, MR fluid system **170** includes a database **240**. Database **240** is, in one embodiment, an electronic data structure stored in memory **210** or another data store and that is configured with routines that may be executed by processor(s) **110** for analyzing stored data, providing stored data, organizing stored data, and so on. Thus, in one embodiment, database **240** stores data used by the detection module **220** and command module **230** in executing various functions. In one embodiment, database **240** includes sensor data **250** along with, for example, metadata that characterize various aspects of sensor data **250**. For example, the metadata may include location coordinates (e.g., longitude and latitude), relative map coordinates or tile identifiers, time/date stamps from when separate sensor data **250** was generated, and so on.

[0026] In one embodiment, command module **230** generally includes instructions that function to control the processor(s) **110** or collection of processors in the cloud-computing environment **300** as shown in FIG. **3** for implementing cooling or EMI shielding strategies.

[0027] With reference to FIG. **3**, vehicle **100** may be connected to a network **305**, which allows for communication between vehicle **100** and cloud servers (e.g., cloud server **310**), infrastructure devices (e.g., infrastructure device **340**), other vehicles (e.g., vehicle **380**), and any other systems connected to network **305**. With respect to network **305**, such a network may use any form of communication or networking to exchange data, including but not limited to the Internet, Directed Short Range Communication (DSRC) service, LTE, 5G, millimeter wave (mmWave) communications, and so on.

[0028] Cloud server **310** is shown as including a processor **315** that may be a part of MR fluid system **170** through network **305** via communication unit **335**. In one embodiment, cloud server **310** includes a memory **320** that stores a communication module **325**. Memory **320** is a random-access memory (RAM), read-only memory (ROM), a hard-disk drive, a flash memory, or other suitable memory for storing communication module **325**. Communication module **325** is, for example, computer-readable instructions that when executed by processor **315** cause processor **315** to perform the various functions disclosed herein. Moreover, in one embodiment, cloud server **310** includes database **330**. Database **330** is, in one embodiment, an electronic data structure stored in a memory **320** or another data store and that is configured with routines that may be executed by processor **315** for analyzing stored data, providing stored data, organizing stored data, and so on.

[0029] Infrastructure device **340** is shown as including a processor **345** that may be a part of MR fluid system **170** through network **305** via communication unit **370**. In one embodiment, infrastructure device **340** includes a memory **350** that stores a communication module **355**. Memory **350** is a random-access memory (RAM), read-only memory (ROM), a hard-disk drive, a flash memory, or other suitable memory for storing communication module **355**. Communication module **355** is, for example, computer-readable instructions that when executed by processor **345** causes processor **345** to perform the various functions disclosed herein. Moreover, in one embodiment, infrastructure device **340** includes a database **360**. Database **360** is, in one embodiment, an electronic data structure stored in memory **350** or another data store and that is configured with routines that may be executed by processor **345** for analyzing stored data, providing stored data, organizing stored data, and so on.

[0030] Accordingly, in addition to information obtained from sensor data **250**, MR fluid system **170** may obtain information from cloud servers (e.g., cloud server **310**), infrastructure devices (e.g., infrastructure device **340**), other vehicles (e.g., vehicle **380**), and any other systems connected to network **305**. For example, cloud servers (e.g., cloud server **310**) may be used to perform the same tasks as described herein with respect to command module **230**. For example, infrastructure device **340** may detect within its coverage area a vehicle in need of wireless charging, such that infrastructure device **340** may determine when the vehicle should engage MR fluid-based cooling or shielding strategies prior to the start of wireless charging.

[0031] With respect to FIG. **4**, an example of MR fluid system **400** is shown, which may be operated as part of MR fluid system **170**. MR fluid system **400** may be comprised of an MR loop **410** containing an MR fluid. MR fluid system may also be comprised of a heat exchanger **420**. MR loop **410** may also contain a swing check valve **430**. In some embodiments, MR fluid system **400** may also include MR fluid driver **450**.

[0032] With respect to heat exchanger **420**, cooling of the MR fluid may be performed using radiators, condensers, heat exchangers, and so on. For example, MR fluid may arrive at heat exchanger **420** at 105 degrees C. for cooling, then be cooled to 65 degrees C. Such cooling may be performed using radiators, condensers, heat exchangers, and so on to exchange heat from the MR fluid to another medium, such as air, water, ethylene glycol, a mix of water and ethylene glycol, etc.

[0033] As shown in FIG. **4**, swing check valve **430** may operate to ensure that MR fluid after heating can only enter into heat exchanger **420** from one direction. Further, MR loop **410** may be comprised of a spiral configuration structure **440**, such that MR fluid upon entering spiral configuration structure **440** proceeds to an area most in need of cooling (e.g., the center of a receiver coil as shown, where magnetic field activity may be strongest) and then follows the spiral to an area less in need of cooling (e.g., the outer area of the receiver coil, where magnetic field activity may be weakest). In some embodiments, the MR fluid may also be relied on to provide EMI shielding in such a configuration in addition to or regardless of any cooling by MR fluid.

[0034] Generally, MR fluid when cooled may be in state where the magnetic fields of the element being cooled more fully magnetize (attract) the nanoparticles within the MR fluid, while the MR fluid when heated may be in a state where the magnetic fields of the element being cooled magnetize (attract) the nanoparticles within the MR fluid to a lesser extent. With respect to FIG. **4**, the shading of the device being cooled (not labeled) indicates both increasing heat and magnetic field strength toward the center. Accordingly, as cooled MR fluid leaves heat exchanger **420**, it may be attracted toward the device being cooled by the magnetic fields the device generates. In some embodiments, an additional magnetic field (e.g., arising from a magnet or dc signal provided by MR fluid driver **450**) may also be used to initially trigger MR fluid to begin flowing in a certain direction within MR loop. In some embodiments, MR fluid driver **450** may be disabled once the desired flow occurs, while in other embodiments the intensity of the magnetic field generated by MR fluid driver **450** may be modulated (e.g., to increase or decrease the flow rate or pumping power based on the use of the device being cooled).

[0035] In some embodiments, the path of MR loop **410** within the spiral configuration structure **440** may be constrained by a field gradient. For example, after the path of MR loop **410** within the spiral configuration structure **440** reaches the area most in need of cooling, a temperature field gradient may be used to ensure that the path of MR loop **410** within the spiral configuration structure **440** proceeds only from a hotter to cooler area. For example, the path of MR loop **410** may be constrained such that after the hottest section any two points on the path of MR loop **410** within the spiral configuration structure **440** indicate a negative rate of temperature change. In some embodiments, two points on the path of MR loop **410** within the spiral configuration structure **440** may be required to satisfy criteria relative to a field gradient (e.g., satisfying a minimum negative rate of temperature change).

[0036] As shown in FIG. **5**A, an example of MR fluid system **500** is shown, which may also be operated as part of MR fluid system **170**. In this embodiment, a set of MR loops **510** (e.g., MR loop **510***a*, MR loop **510***b*, . . . , MR loop **510***n*) may be used to cool an element, such as a receiver coil as shown. In addition, another cooling loop **520** may be used to cool MR loops **510**. While cooling loop **520** is shown as one loop, other forms of cooling may also be used, such as multiple loops, multiple heat exchangers, etc.

[0037] In some embodiments, the MR loops **510** may at least be partially routed through star-shaped configuration structure **530** as shown, such that an end of each MR loop within MR loops **510** is located in an area of star-shaped configuration structure **530** most in need of cooling (e.g., at or near the center of a receiver coil as shown by shading, where magnetic field activity may be strongest), after which both parts of that MR loop may proceed directly out to an area of star-shaped configuration structure **530** less in need of cooling (e.g., the outer area of the receiver coil, where magnetic field activity may be weakest) and then to the other respective end of the loop at cooling loop **520**. In some embodiments, MR loops **510** may only reside partially within star-shaped configuration structure **530** while cooling loop **520** is external to star-shaped configuration structure **530**. In some embodiments, MR loops **510** and cooling loop **520** may fully reside partially within star-shaped configuration structure **530**.

[0038] As shown in FIG. **5**B, a cooling system **550** is shown using MR fluid flow driven by magnetic fields and MR fluid intrinsics, which may be used for each MR loop in MR fluid system **500**. MR loop **570** may contain MR fluid **580**, which may be coolest where heat sink **560** is coupled to MR loop **570**. As hot MR fluid enters heat sink **560** it may cool MR fluid **580** such that the nanoparticles within become more magnetized (attracted) to a magnetic field. In some embodiments, the magnetic field generated by the device being cooled (e.g., device **555**) may be sufficient to magnetize (attract) the nanoparticles in MR fluid **580** after leaving the heat exchanger **560**. In some embodiments, MR fluid driver **565** may provide a magnetic signal, such as by a magnet or dc signal to initiate or drive MR fluid flow via the nanoparticles. As MR fluid **580** approaches the stronger magnetic fields, it may approach the hottest section of device **555**, during which the heating of MR fluid **580** may cause the nanoparticles therein to become significantly less magnetized (attracted) by the magnetic field **590** generated by device **555**. Accordingly, the cooler MR fluid **580** may be strongly magnetized (attracted) toward the area of strongest magnetic attraction while the hotter MR fluid **580** flows back to heat exchanger **560** due to its reduced magnetization (attraction) to magnetic fields. In some embodiments, a swing check valve (not shown) may be incorporated into MR loop **570** after heat sink **560** or MR fluid driver **565** if present to constrain MR fluid flow.

[0039] FIG. **6** illustrates a flowchart of a method **600** that is associated with MR fluid-based cooling or shielding strategies. Method **600** will be discussed from the perspective of the MR fluid system **170** of FIGS. **1** and **2**. While method **600** is discussed in combination with the MR fluid system **170**, it should be appreciated that the method **600** is not limited to being implemented within MR fluid system **170** but is instead one example of a system that may implement method **600**.

[0040] At **610**, MR fluid system **170** may store MR fluid in an MR loop, which may be MR loop **410** or part of MR loops **510**. In some embodiments, the MR loop may be equipped with temperature sensors, pressure sensors, and so on to determine the state of the MR fluid.

[0041] At **620**, MR fluid system **170** may utilize a heat exchanger coupled to the MR loop to cool the MR fluid. For example, heat from the MR fluid may be exchanged with another medium such as air, water, ethylene glycol, a mix of water and ethylene glycol, etc. via a heat exchanger, a cooling loop, and so on.

[0042] At **630**, MR fluid system **170** may utilize a swing check valve within the MR loop to constrain the flow of the MR fluid to one direction.

[0043] At **640**, MR fluid system **170** may utilize a structure forming a segment of the MR loop where the MR fluid provides cooling, electromagnetic interference shielding, or both to a vehicular component. For example, the structure may consist of a spiral configuration structure that injects MR flood into the hottest area of the structure than spirals out into cooler areas of the structure.

[0044] FIG. **1** will now be discussed in full detail as an example environment within which the system and methods disclosed herein may operate. In some instances, vehicle **100** is configured to switch selectively between various modes, such as an autonomous mode, one or more semi-autonomous operational modes, a manual mode, etc. Such switching may be implemented in a suitable manner, now known, or later developed. "Manual mode" means that all of or a majority of the navigation/maneuvering of the vehicle is performed according to inputs received from a user (e.g., human driver). In one or more arrangements, vehicle **100** may be a conventional vehicle that is configured to operate in only a manual mode.

[0045] In one or more embodiments, vehicle **100** is an autonomous vehicle. As used herein, "autonomous vehicle" refers to a vehicle that operates in an autonomous mode. "Autonomous mode" refers to using one or more computing systems to control vehicle **100**, such as providing navigation/maneuvering of vehicle **100** along a travel route, with minimal or no input from a human driver. In one or more embodiments, vehicle **100** is either highly automated or completely automated. In one embodiment, vehicle **100** is configured with one or more semi-autonomous operational modes in which one or more computing systems perform a portion of the navigation/maneuvering of the vehicle along a travel route, and a vehicle operator (i.e., driver) provides inputs to the vehicle to perform a portion of the navigation/maneuvering of vehicle **100** along a travel route.

[0046] Vehicle **100** may include one or more processors **110**. In one or more arrangements, processor(s) **110** may be a main processor of vehicle **100**. For instance, processor(s) **110** may be an electronic control unit (ECU). Vehicle **100** may include one or more data stores **115** for storing one or more types of data. Data store(s) **115** may include volatile memory, non-volatile memory, or both. Examples of suitable data store(s) **115** include RAM (Random Access Memory), flash memory, ROM (Read Only Memory), PROM (Programmable Read-Only Memory), EPROM (Erasable Programmable Read-Only Memory), EEPROM

(Electrically Erasable Programmable Read-Only Memory), registers, magnetic disks, optical disks, hard drives, or any other suitable storage medium, or any combination thereof. Data store(s) **115** may be a component of processor(s) **110**, or data store **115** may be operatively connected to processor (s) **110** for use thereby. The term "operatively connected," as used throughout this description, may include direct or indirect connections, including connections without direct physical contact.

[0047] In one or more arrangements, data store(s) **115** may include map data **116**. Map data **116** may include maps of one or more geographic areas. In some instances, map data **116** may include information or data on roads, traffic control devices, road markings, structures, features, landmarks, or any combination thereof in the one or more geographic areas. Map data **116** may be in any suitable form. In some instances, map data **116** may include aerial views of an area. In some instances, map data **116** may include ground views of an area, including 360-degree ground views. Map data **116** may include measurements, dimensions, distances, information, or any combination thereof for one or more items included in map data **116**. Map data **116** may also include measurements, dimensions, distances, information, or any combination thereof relative to other items included in map data **116**. Map data **116** may include a digital map with information about road geometry. Map data **116** may be high quality, highly detailed, or both.

[0048] In one or more arrangements, map data **116** may include one or more terrain maps **117**. Terrain map(s) **117** may include information about the ground, terrain, roads, surfaces, other features, or any combination thereof of one or more geographic areas. Terrain map(s) **117** may include elevation data in the one or more geographic areas. Terrain map(s) **117** may be high quality, highly detailed, or both. Terrain map(s) **117** may define one or more ground surfaces, which may include paved roads, unpaved roads, land, and other things that define a ground surface.

[0049] In one or more arrangements, map data **116** may include one or more static obstacle maps **118**. Static obstacle map(s) **118** may include information about one or more static obstacles located within one or more geographic areas. A "static obstacle" is a physical object whose position does not change or substantially change over a period of time and whose size does not change or substantially change over a period of time. Examples of static obstacles include trees, buildings, curbs, fences, railings, medians, utility poles, statues, monuments, signs, benches, furniture, mailboxes, large rocks, hills. The static obstacles may be objects that extend above ground level. The one or more static obstacles included in static obstacle map(s) **118** may have location data, size data, dimension data, material data, other data, or any combination thereof, associated with it. Static obstacle map(s) **118** may include measurements, dimensions, distances, information, or any combination thereof for one or more static obstacles. Static obstacle map(s) **118** may be high quality, highly detailed, or both. Static obstacle map(s) **118** may be updated to reflect changes within a mapped area.

[0050] Data store(s) **115** may include sensor data **119**. In this context, "sensor data" means any information about the sensors that vehicle **100** is equipped with, including the capabilities and other information about such sensors. As will be explained below, vehicle **100** may include sensor system **120**. Sensor data **119** may relate to one or more sensors of sensor system **120**. As an example, in one or more arrangements, sensor data **119** may include information on one or more LIDAR sensors **124** of sensor system **120**.

[0051] In some instances, at least a portion of map data **116** or sensor data **119** may be located in data stores(s) **115** located onboard vehicle **100**. Alternatively, or in addition, at least a portion of map data **116** or sensor data **119** may be located in data stores(s) **115** that are located remotely from vehicle **100**.

[0052] As noted above, vehicle **100** may include sensor system **120**. Sensor system **120** may include one or more sensors. "Sensor" means any device, component, or system that may detect or sense something. The one or more sensors may be configured to sense, detect, or perform both in real-time. As used herein, the term "real-time" means a level of processing responsiveness that a user or system senses as sufficiently immediate for a particular process or determination to be made, or that enables the processor to keep up with some external process.

[0053] In arrangements in which sensor system **120** includes a plurality of sensors, the sensors may work independently from each other. Alternatively, two or more of the sensors may work in combination with each other. In such an embodiment, the two or more sensors may form a sensor network. Sensor system **120**, the one or more sensors, or both may be operatively connected to processor(s) **110**, data store(s) **115**, another element of vehicle **100** (including any of the elements shown in FIG. **1**), or any combination thereof. Sensor system **120** may acquire data of at least a portion of the external environment of vehicle **100** (e.g., nearby vehicles).

[0054] Sensor system **120** may include any suitable type of sensor. Various examples of different types of sensors will be described herein. However, it will be understood that the embodiments are not limited to the particular sensors described. Sensor system **120** may include one or more vehicle sensors **121**. Vehicle sensor(s) **121** may detect, determine, sense, or acquire in a combination thereof information about vehicle **100** itself. In one or more arrangements, vehicle sensor(s) **121** may be configured to detect, sense, or acquire in a combination thereof position and orientation changes of vehicle **100**, such as, for example, based on inertial acceleration. In one or more arrangements, vehicle sensor(s) **121** may include one or more accelerometers, one or more gyroscopes, an inertial measurement unit (IMU), a dead-reckoning system, a global navigation satellite system (GNSS), a global positioning system (GPS), a navigation system **147**, other suitable sensors, or any combination thereof. Vehicle sensor(s) **121** may be configured to detect, sense, or acquire in a combination thereof one or more characteristics of vehicle **100**. In one or more arrangements, vehicle sensor(s) **121** may include a speedometer to determine a current speed of vehicle **100**.

[0055] Alternatively, or in addition, sensor system **120** may include one or more environment sensors **122** configured to acquire, sense, or acquire in a combination thereof driving environment data. "Driving environment data" includes data or information about the external environment in which an autonomous vehicle is located or one or more portions thereof. For example, environment sensor(s) **122** may be configured to detect, quantify, sense, or acquire in any combination thereof obstacles in at least a portion of the external environment of vehicle **100**, information/data about such obstacles, or a combination thereof. Such obstacles may be comprised of stationary objects, dynamic objects, or a combination thereof. Environment sensor(s) **122** may be configured to detect, measure, quantify, sense, or acquire in any combination thereof other things in the external environment of vehicle **100**, such as, for example, lane markers, signs, traffic lights, traffic signs, lane lines, crosswalks, curbs proximate to vehicle **100**, off-road objects, etc.

[0056] Various examples of sensors of sensor system **120** will be described herein. The example sensors may be part of the one or more environment sensor(s) **122**, the one or more vehicle sensors **121**, or both. However, it will be understood that the embodiments are not limited to the particular sensors described.

[0057] As an example, in one or more arrangements, sensor system **120** may include one or more radar sensors **123**, one or more LIDAR sensors **124**, one or more sonar sensors **125**, one or more cameras **126**, or any combination thereof. In one or more arrangements, camera(s) **126** may be high dynamic range (HDR) cameras or infrared (IR) cameras.

[0058] Vehicle **100** may include an input system **130**. An "input system" includes any device, component, system, element or arrangement or groups thereof that enable information/data to be entered into a machine. Input system **130** may receive an input from a vehicle passenger (e.g., a driver or a passenger). Vehicle **100** may include an output system **135**. An "output system" includes any device, component, or arrangement or groups thereof that enable information/data to be presented to a vehicle passenger (e.g., a person, a vehicle passenger, etc.).

[0059] Vehicle **100** may include one or more vehicle systems **140**. Various examples of vehicle system(s) **140** are shown in FIG. **1**. However, vehicle **100** may include more, fewer, or different vehicle systems. It should be appreciated that although particular vehicle systems are separately defined, each or any of the systems or portions thereof may be otherwise combined or segregated via hardware, software, or a combination thereof within vehicle **100**. Vehicle **100** may include a propulsion system **141**, a braking system **142**, a steering system **143**, throttle system **144**, a transmission system **145**, a signaling system **146**, a navigation system **147**, other systems, or any combination thereof. Each of these systems may include one or more devices, components, or combinations thereof, now known or later developed.

[0060] Navigation system **147** may include one or more devices, applications, or combinations thereof, now known or later developed, configured to determine the geographic location of the vehicle **100**, to determine a travel route for vehicle **100**, or to determine both. Navigation system **147** may include one or more mapping applications to determine a travel route for vehicle **100**. Navigation system **147** may include a global positioning system, a local positioning system, a geolocation system, or any combination thereof.

[0061] Processor(s) **110**, MR fluid system **170**, automated driving module(s) **160**, or any combination thereof may be operatively connected to communicate with various aspects of vehicle system(s) **140** or individual components thereof. For example, returning to FIG. **1**, processor(s) **110**, automated driving module(s) **160**, or a combination thereof may be in communication to send or receive information from various aspects of vehicle system(s) **140** to control the movement, speed, maneuvering, heading, direction, etc. of vehicle **100**. Processor(s) **110**, MR fluid system **170**, automated driving module(s) **160**, or any combination thereof may control some or all of these vehicle system(s) **140** and, thus, may be partially or fully autonomous.

[0062] Processor(s) **110**, MR fluid system **170**, automated driving module(s) **160**, or any combination thereof may be operable to control at least one of the navigation or maneuvering of vehicle **100** by controlling one or more of vehicle systems **140** or components thereof. For instance, when operating in an autonomous mode, processor(s) **110**, MR fluid system **170**, automated driving module(s) **160**, or any combination thereof may control the direction, speed, or both of vehicle **100**. Processor(s) **110**, MR fluid system **170**, automated driving module(s) **160**, or any combination thereof may cause vehicle **100** to accelerate (e.g., by increasing the supply of fuel provided to the engine), decelerate (e.g., by decreasing the supply of fuel to the engine, by applying brakes), change direction (e.g., by turning the front two wheels), or perform any combination thereof. As used herein, "cause" or "causing" means to make, force, compel, direct, command, instruct, enable, or in any combination thereof an event or action to occur or at least be in a state where such event or action may occur, either in a direct or indirect manner.

[0063] Vehicle **100** may include one or more actuators **150**. Actuator(s) **150** may be any element or combination of elements operable to modify, adjust, alter, or in any combination thereof one or more of vehicle systems **140** or components thereof to responsive to receiving signals or other inputs from processor(s) **110**, automated driving module(s) **160**, or a combination thereof. Any suitable actuator may be used. For instance, actuator(s) **150** may include motors, pneumatic actuators, hydraulic pistons, relays, solenoids, and piezoelectric actuators, just to name a few possibilities.

[0064] Vehicle **100** may include one or more modules, at least some of which are described herein. The modules may be implemented as computer-readable program code that, when executed by processor(s) **110**, implement one or more of the various processes described herein. One or more of the modules may be a component of processor(s) **110**, or one or more of the modules may be executed on or distributed among other processing systems to which processor(s) **110** is operatively connected. The modules may include instructions (e.g., program logic) executable by processor(s) **110**. Alternatively, or in addition, data store(s) **115** may contain such instructions.

[0065] In one or more arrangements, one or more of the modules described herein may include artificial or computational intelligence elements, e.g., neural network, fuzzy logic, or other machine learning algorithms. Further, in one or more arrangements, one or more of the modules may be distributed among a plurality of the modules described herein. In one or more arrangements, two or more of the modules described herein may be combined into a single module.

[0066] Vehicle **100** may include one or more autonomous driving modules **160**. Automated driving module(s) **160** may be configured to receive data from sensor system **120** or any other type of system capable of capturing information relating to vehicle **100**, the external environment of the vehicle **100**, or a combination thereof. In one or more arrangements, automated driving module(s) **160** may use such data to generate one or more driving scene models. Automated driving module(s) **160** may determine position and velocity of vehicle **100**. Automated driving module(s) **160** may determine the location of obstacles, obstacles, or other environmental features including traffic signs, trees, shrubs, neighboring vehicles, pedestrians, etc.

[0067] Automated driving module(s) **160** may be configured to receive, determine, or in a combination thereof location information for obstacles within the external environment of vehicle **100**, which may be used by processor(s) **110**, one or more of the modules described herein, or any combination thereof to estimate: a position or orientation of vehicle **100**; a vehicle position or orientation in global coordinates based on signals from a plurality of satellites or other geolocation systems; or any other data/signals that could be used to determine a position or orientation of vehicle **100** with respect to its environment for use in either creating a map or determining the position of vehicle **100** in respect to map data.

[0068] Automated driving module(s) **160** either independently or in combination with MR fluid system **170** may be configured to determine travel path(s), current autonomous driving maneuvers for vehicle **100**, future autonomous driving maneuvers, modifications to current autonomous driving maneuvers, etc. Such determinations by automated driving module(s) **160** may be based on data acquired by sensor system **120**, driving scene models, data from any other suitable source such as determinations from sensor data **250**, or any combination thereof. In general, automated driving module(s) **160** may function to implement different levels of automation, including advanced driving assistance (ADAS) functions, semi-autonomous functions, and fully autonomous functions. "Driving maneuver" means one or more actions that affect the movement of a vehicle. Examples of driving maneuvers include accelerating, decelerating, braking, turning, moving in a lateral direction of vehicle **100**, changing travel lanes, merging into a travel lane, and reversing, just to name a few possibilities. Automated driving module(s) **160** may be configured to implement driving maneuvers. Automated driving module(s) **160** may cause, directly or indirectly, such autonomous driving maneuvers to be implemented. As used herein, "cause" or "causing" means to make, command, instruct, enable, or in any combination thereof an event or action to occur or at least be in a state where such event or action may occur, either in a direct or indirect manner. Automated driving module(s) **160** may be configured to execute various vehicle functions, whether individually or in combination, to transmit data to, receive data from, interact with, or to control vehicle **100** or one or more systems thereof (e.g., one or more of vehicle systems **140**).

[0069] Detailed embodiments are disclosed herein. However, it is to be understood that the disclosed embodiments are intended only as examples. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a basis for the claims and as a representative basis for teaching one skilled in the art to variously employ the aspects herein in virtually any appropriately detailed structure. Further, the terms and phrases used herein are not intended to be limiting but rather to provide an understandable description of possible implementations. Various embodiments are shown in FIGS. **1-6**, but the embodiments are not limited to the illustrated structure or application.

[0070] The flowcharts and block diagrams in the figures illustrate the architecture, functionality, and operation of possible implementations of systems, methods, and computer program products according to various embodiments. In this regard, each block in the flowcharts or block diagrams may represent a module, segment, or portion of code, which comprises one or more executable instructions for implementing the specified logical function(s). It should also be noted that, in some alternative implementations, the functions noted in the block may occur out of the order noted in the figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved.

[0071] The systems, components, or processes described above may be realized in hardware or a combination of hardware and software and may be realized in a centralized fashion in one processing system or in a distributed fashion where different elements are spread across several interconnected processing systems. Any kind of processing system or another apparatus adapted for carrying out the methods described herein is suited. A typical combination of hardware and software may be a processing system with computer-usable program code that, when being loaded and executed, controls the processing system such that it carries out the methods described herein. The systems, components, or processes also may be embedded in a computer-readable storage, such as a computer program product or other data programs storage device, readable by a machine, tangibly embodying a program of instructions executable by the machine to perform methods and processes described herein. These elements also may be embedded in an application product which comprises all the features enabling the implementation of the methods described herein and, which when loaded in a processing system, is able to carry out these methods.

[0072] Furthermore, arrangements described herein may take the form of a computer program product embodied in one or more computer-readable media having computer-readable program code embodied, e.g., stored, thereon. Any combination of one or more computer-readable media may be utilized. The computer-readable medium may be a computer-readable signal medium or a computer-readable storage medium. The phrase "computer-readable storage medium" means a non-transitory storage medium. A computer-readable storage medium may be, for example, but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, or device, or any suitable combination of the foregoing. More specific examples (a non-exhaustive list) of the computer-readable storage medium would include the following: a portable computer diskette, a hard disk drive (HDD), a solid-state drive (SSD), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), a portable compact disc read-only memory (CD-ROM), a digital versatile disc (DVD), an optical storage device, a magnetic storage device, or any suitable combination of the foregoing. In the context of this document, a computer-readable storage medium may be any tangible medium that may contain or store a program for use by or in connection with an instruction execution system, apparatus, or device.

[0073] Generally, modules as used herein include routines, programs, objects, components, data structures, and so on that perform particular tasks or implement particular data types. In further aspects, a memory generally stores the noted modules. The memory associated with a module may be a buffer or cache embedded within a processor, a RAM, a ROM, a flash memory, or another suitable electronic storage medium. In still further aspects, a module as envisioned by the present disclosure is implemented as an application-specific integrated circuit (ASIC), a hardware component of a system on a chip (SoC), as a programmable logic array (PLA), or as another suitable hardware component that is embedded with a defined configuration set (e.g., instructions) for performing the disclosed functions.

[0074] Program code embodied on a computer-readable medium may be transmitted using any appropriate medium, including but not limited to wireless, wireline, optical fiber, cable, RF, etc., or any suitable combination of the foregoing. Computer program code for carrying out operations for aspects of the present arrangements may be written in any combination of one or more programming languages, including an object-oriented programming language such as Java™, Smalltalk, C++, or the like and conventional procedural programming languages, such as the "C" programming language or similar programming languages. The program code may execute entirely on a user's computer, partly on the user's computer, as a stand-alone software package, partly on the user's computer and partly on a remote computer, or entirely on the remote computer or server. In the latter scenario, the remote computer may be connected to the user's computer through any type of network, including a local area network (LAN) or a wide area network (WAN), or the connection may be made to an external computer (for example, through the Internet using an Internet Service Provider).

[0075] The terms "a" and "an," as used herein, are defined as one or more than one. The term "plurality," as used herein, is defined as two or more than two. The term "another," as used herein, is defined as at least a second or more. The terms "including" and "having," as used herein, are defined as comprising (i.e., open language). The phrase "at least one of . . . and . . . " as used herein refers to and encompasses any and all possible combinations of one or more of the associated listed items. As an example, the phrase "at least one of A, B, and C" includes A only, B only, C only, or any combination thereof (e.g., AB, AC, BC, or ABC).

[0076] Aspects herein may be embodied in other forms without departing from the spirit or essential attributes thereof. Accordingly, reference should be made to the following claims, rather than to the foregoing specification, as indicating the scope hereof.

What is claimed is:

1. A system, comprising:

a loop containing magnetorheological fluid;

a heat exchanger coupled to the loop to cool the magnetorheological fluid;

a swing check valve within the loop to constrain flow of the magnetorheological fluid; and

a structure forming a segment of the loop where the magnetorheological fluid provides cooling to a vehicular component.

2. The system of claim **1**, wherein the structure routes a portion of the segment according to a temperature field gradient.

3. The system of claim **2**, wherein the structure routes the portion of the segment in a spiral configuration.

4. The system of claim **1**, wherein the segment upon receiving magnetorheological fluid follows a path directly toward hottest area of the structure.

5. The system of claim **1**, wherein the magnetorheological fluid provides electromagnetic interference shielding to the vehicular component.

6. The system of claim **5**, wherein the vehicular component is a sensor.

7. The system of claim **1**, wherein the vehicular component is not an electronic component.

8. A system, comprising:

a set of loops containing magnetorheological fluid;

a heat exchanger coupled to the set of loops to cool the magnetorheological fluid; and

a structure forming a corresponding segment of each loop where the magnetorheological fluid provides cooling to a vehicular component.

9. The system of claim **8**, wherein the structure routes each corresponding segment according to a temperature field gradient.

10. The system of claim **9**, wherein each loop contains a swing check valve within the loop to constrain the flow of the magnetorheological fluid.

11. The system of claim **9**, wherein the structure routes each corresponding segment of each loop to form a star-shaped configuration.

12. The system of claim **8**, wherein the magnetorheological fluid provides electromagnetic interference shielding to the vehicular component.

13. The system of claim **12**, wherein the vehicular component is a sensor.

14. A method, comprising:

storing magnetorheological fluid in a loop;

utilizing a heat exchanger coupled to the loop to cool the magnetorheological fluid;

utilizing a swing check valve within the loop to constrain flow of the magnetorheological fluid; and

utilizing a structure forming a segment of the loop where the magnetorheological fluid provides cooling to a vehicular component.

15. The method of claim **14**, wherein the structure routes a portion of the segment according to a temperature field gradient.

16. The method of claim **15**, wherein the structure routes the portion of the segment in a spiral configuration.

17. The method of claim **14**, wherein the segment upon receiving the magnetorheological fluid follows a path directly toward hottest area of the structure.

18. The method of claim **14**, wherein the magnetorheological fluid provides electromagnetic interference shielding to the vehicular component.

19. The method of claim **18**, wherein the vehicular component is a sensor.

20. The method of claim **14**, wherein the vehicular component is not an electronic component.

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