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## VIBRATION REDUCTION MECHANISM FOR ELECTRIC DRIVE MODULE

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### Abstract

An electric drive module for an electrified vehicle includes an electric motor, a transmission, a multispeed actuation mechanism (MAM), and a controller. The transmission is driven by a rotatable output of the electric motor and includes a first drive shaft and a second drive shaft. The transmission has a first gear set that selectively converts rotatable motion of the first drive shaft into rotatable motion of the second drive shaft in a first gear mode, and a second gear set that selectively converts rotatable motion of the first drive shaft into rotatable motion of the second drive shaft in a second gear mode. The MAM has magnetic fluid therein that activates causing selective rotatable communication between the first and second drive shafts. The controller commands activation of the MAM whereby a limited slip condition occurs between the first and second drive shafts thereby mitigating vibrations in the electric drive module.

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## Background/Summary

### FIELD

[0001] The present application generally relates to electrified vehicles and, more particularly, to an electric drive module that uses a vibration reduction mechanism having magnetic fluid.

### BACKGROUND

[0002] An electrified vehicle (hybrid electric, plug-in hybrid electric, range-extended electric, battery electric, etc.) includes at least one battery system and at least one electric motor. Typically, the electrified vehicle would include a high voltage battery system and a low voltage (e.g., 12 volt) battery system. In such a configuration, the high voltage battery system is utilized to power at least one electric motor configured on the vehicle and to recharge the low voltage battery system via a direct current to direct current (DC-DC) convertor.

[0003] Electrified vehicles generally include a powertrain configured to generate and transfer drive torque to a driveline of the vehicle for propulsion. The electrified powertrain generally comprises the high voltage battery system, one or more electric motors, and a transmission. The electric motors and transmission can be referred to as an electric drive module. Some electric drive modules can incorporate conventional clutch systems that allow the transmission to shift between more than one gear. Conventional clutch systems require components such as a pump, valves, solenoids to support its functions. These components can result in a power loss of the electrified powertrain as a whole. Furthermore, such clutch systems transmit undesirable noise vibration and harshness (NVH) into the vehicle based on mechanical connections between input and output shafts. Accordingly, while such electric drive modules having transmissions using conventional clutch systems do work well for their intended purpose, there exists an opportunity for improvement in the relevant art.

### SUMMARY

[0004] According to one example aspect of the invention, an electric drive module for an electrified vehicle includes an electric motor, a transmission, a multispeed actuation mechanism (MAM), and a controller. The transmission is driven by a rotatable output of the electric motor and includes a first drive shaft and a second drive shaft. The transmission has a first gear set that selectively converts rotatable motion of the first drive shaft into rotatable motion of the second drive shaft in a first gear mode at a first drive ratio, and a second gear set that selectively converts rotatable motion of the first drive shaft into rotatable motion of the second drive shaft in a second gear mode at a second drive ratio, distinct from the first drive ratio. The MAM has magnetic fluid therein. Activation of the magnetic fluid causes selective rotatable communication between the first and second drive shafts. The controller commands activation of the MAM whereby a limited slip condition occurs between the first and second drive shafts thereby mitigating vibrations in the electric drive module.

[0005] In some implementations, the controller commands a predetermined amount of activation of the MAM corresponding to a predetermined acceptable level of vibrations.

[0006] In additional arrangements, the controller commands activation of the MAM thereby reducing torque fluctuations within the electric drive module.

[0007] In additional features, the magnetic fluid includes ferromagnetic nanoparticles suspended therein. The MAM is configured to receive an activation signal from the controller based on sensor inputs of the electrified vehicle indicative of a shift change request.

[0008] In some implementations, the MAM further includes a first disk and a second disk. Activation of the magnetic fluid results in the first and second disks moving from a disengaged position to an at least partially engaged position. The first gear set comprises a first gear configured to rotate with the first drive shaft and a second gear that is configured to selectively drive the

second drive shaft in a first gear mode. The second gear set comprises a first gear configured to rotate with the first drive shaft and a second gear that is configured to selectively rotate with the second drive shaft in a second gear mode.

[0009] In additional arrangements, the first and second disks at least partially engage to couple for rotation the first drive shaft with the first gear of the second gear set. The second drive shaft is rotatably coupled to drive axles that drive respective drive wheels through a differential.

[0010] According to another example aspect of the invention, an electric drive module for an electrified vehicle includes a transmission and a multispeed actuation mechanism (MAM). The transmission is driven by a rotatable output of an electric motor and includes a first drive shaft and a second drive shaft. The transmission has a first gear set that selectively converts rotatable motion of the first drive shaft into rotatable motion of the second drive shaft in a first gear mode at a first drive ratio, and a second gear set that selectively converts rotatable motion of the first drive shaft into rotatable motion of the second drive shaft in a second gear mode at a second drive ratio, distinct from the first drive ratio. The MAM has a first disk rotatably coupled to an input shaft and a second disk rotatably coupled to an output shaft. The MAM includes magnetic fluid therein. Activation of the magnetic fluid causes the first and second disks to rotate concurrently and a shift to occur within the transmission from the first gear set to the second gear set.

[0011] In some implementations, the magnetic fluid includes ferromagnetic nanoparticles suspended therein. The MAM is configured to receive an activation signal from a controller based on sensor inputs of the electrified vehicle indicative of a shift change request.

[0012] In some implementations, the first gear set comprises a first gear configured to rotate with the first drive shaft and a second gear that is configured to selectively drive the second drive shaft in the first gear mode. The second gear set comprises a first gear configured to rotate with the first drive shaft and a second gear that is configured to selectively rotate with the second drive shaft in the second gear mode.

[0013] In additional arrangements, the first and second disks engage to couple for rotation the first drive shaft with the first gear of the second gear set. The second drive shaft is rotatably coupled to drive axles that drive respective drive wheels through a differential.

[0014] Further areas of applicability of the teachings of the present application will become apparent from the detailed description, claims and the drawings provided hereinafter, wherein like reference numerals refer to like features throughout the several views of the drawings. It should be understood that the detailed description, including disclosed embodiments and drawings referenced therein, are merely exemplary in nature intended for purposes of illustration only and are not intended to limit the scope of the present disclosure, its application or uses. Thus, variations that do not depart from the gist of the present application are intended to be within the scope of the present application.

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## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

[0015] FIG. 1 is a functional block diagram of an electrified vehicle having an electric drive module according to the principles of the present application;

[0016] FIG. 2 is a schematic illustration of an electric drive module incorporating a conventional friction clutch according to one Prior Art example;

[0017] FIG. 3 is a schematic illustration of an electric drive module incorporating a multispeed actuation mechanism (MAM) according the principles of the present application;

[0018] FIG. 4 is an exemplary torque input and output model using the MAM of FIG. 3 according to the principles of the present application;

[0019] FIG. 5 is an exemplary plot showing torque/current versus time for the MAM of FIG. 3

according to principles of the present application; and [0020] FIG. 6 is an exemplary schematic illustration of the MAM of FIG. 3 according to principles of the present application.

#### DESCRIPTION

[0021] As discussed above, an electrified powertrain generally includes a high voltage battery system, one or more electric motors, and a transmission. The electric motors and transmission can be referred to as an electric drive module. Some electric drive modules can incorporate conventional clutch systems that allow the transmission to shift between more than one gear. Conventional clutch systems require components such as a pump, valves, solenoids to support its functions. These components can result in a power loss of the electrified powertrain as a whole. Furthermore, such clutch systems transmit undesirable noise vibration and harshness (NVH) into the vehicle based on mechanical connections between input and output shafts.

[0022] Accordingly, the instant application provides a multispeed actuation mechanism (MAM) instead of a conventional clutch to control a shift between gears and reduce NVH. The MAM disclosed herein uses magnetic fluid to engage and disengage rotating members (such as disks) to allow for connection of desired gears. In examples, the magnetic fluid consists of ferromagnetic nanoparticles suspended in fluid. Activation of the magnetic fluid can cause the liquid to change shape and thereby cause first and second shafts to move from a disengaged position to an at least partially engaged position for communicating rotation from the first shaft to the second shaft. In this regard, movement to the at least partially engaged position can cause a transmission to shift from a first gear to a second gear. The MAM is used to reduce NVH in the electrified powertrain and vehicle as a whole. The MAM uses the magnetic fluid to provide limited slip between the input and output for reduction of torque fluctuations resulting in a reduction in NVH. The amount of limited slip is controlled and predetermined by acceptable vibration levels. The reduction in torsional vibrations provided by the MAM can be experienced by a driver making the driving experience smoother and more desirable.

[0023] The MAM makes such shifting between engaged and disengaged positions smooth to the vehicle operator. As used herein an “engaged” position can be defined as a limited slip condition between an input and output such that less than 100% of drive torque is transmitted from the input and output. By allowing the inputs and outputs to at least partially slip, NVH is improved. The amount of limited slip condition is controlled by a controller and facilitates the reduction in NVH. Use of the MAM instead of conventional friction clutches improves efficiency of the electric drive module significantly because of elimination of various components including any pumps, valves, friction and separator plates and solenoids needed for a conventional friction clutch. In addition, incorporation of a MAM according to the present disclosure reduces weight of the drive module.

[0024] Referring now to FIG. 1, a functional block diagram of an example electrified vehicle **100** (also referred to herein as “vehicle **100**”) according to the principles of the present application is illustrated. The vehicle **100** includes an electrified powertrain **104** configured to generate and transfer drive torque to a driveline **108** of the vehicle **100** for propulsion. The electrified powertrain **104** generally comprises a high voltage battery system **112** (also referred to herein as “battery system **112**”), one or more electric motors **116**, and a transmission **120**. The one or more electric motors **116** and the transmission **120** can be collectively referred to herein as an electric drive module **122**. The battery system **112** is selectively connectable (e.g., by the driver) to an external charging system **124** (also referred to herein as “charger **124**”) for charging of the battery system **112**. The transmission **120** receives signals from a controller **130** indicative of a shift request based on information obtained by sensors **136** throughout the vehicle.

[0025] Referring now to FIG. 2, an exemplary drive module constructed in accordance to one Prior Art example is shown and generally identified at reference numeral **210**. The exemplary drive module **210** generally includes an electric motor **216** and a transmission **220** that sends drive torque through a driveline **230**. The driveline **230** can include first and second drive wheels **232**

selectively coupled through drive axles **238** through and a differential **236**. Other arrangements are contemplated.

[0026] The transmission **220** can include an initial gear set **250** including a first gear **252** coupled to an output of the electric motor **216** and that rotatably drives a second gear **254** that drives a first drive shaft **258**. By way of example only the initial gear set **250** can provide a gear ratio of 1.95. Other ratios are contemplated. A first gear set **260** includes a first gear **262** driven by the first drive shaft **258** and that rotates a second gear **264**. In examples, a one way clutch **268** can be provided at the second gear **264**. The second gear **264** can be selectively coupled for rotation with a second drive shaft **270**. A second gear set **280** includes first gear **282** selectively coupled for rotation with the first drive shaft **258**. A second gear **284** is coupled for rotation with the second drive shaft **270**. A friction clutch **286** includes first plates **288** and second plates **290** that selectively engage to couple for rotation the first drive shaft **258** with the first gear **282** of the second gear set **280**.

[0027] The drive module **210** can operate in a first gear using a torque path **292** that flows through the first gear set **260**. By way of example only the first gear set **260** can provide a gear ratio of 2.63. Other ratios are contemplated. The drive module **210** can operate in a second gear using a torque path **294** that flows through the second gear set **280**. A shift from the first torque path **292** to the second torque path **294** can result in actuation of the friction clutch **286**. When the first plates **288** and second plate **290** move from a disengaged position to an engaged position, the first drive shaft **258** is fixed for rotation with the first gear **282** of the second gear set **280**. The first gear **282** in turn rotates the second gear **284** of the second gear set **280**. By way of example only the second gear set **280** can provide a gear ratio of 1.25. Other ratios are contemplated. In examples, the clutch **268** can also be activated thereby eliminating a torque transfer from the first gear **262** of the first gear set **260** to the second drive shaft **270**. Instead, the drive shaft **270** is driven by the second gear set **280** including the first and second gears **282** and **284**.

[0028] Referring now to FIGS. 3-6, an exemplary drive module constructed in accordance to one example of the present disclosure is shown and generally identified at reference numeral **310**. The exemplary drive module **310** generally includes an electric motor **316** and a transmission **320** that sends drive torque through a driveline **330**. The driveline **330** can include first and second drive wheels **332** selectively coupled through drive axles **338** through and a differential **336**. Other arrangements are contemplated.

[0029] The transmission **320** can include an initial gear set **350** including a rotatable output or first gear **352** coupled to an output of the electric motor **316** and that rotatably drives a second gear **354** that drives a first drive shaft **358** in a first gear mode. By way of example only the initial gear set **350** can provide a gear ratio of 1.95. Other ratios are contemplated. A first gear set **360** includes a first gear **362** driven by the first drive shaft **358** and that rotates a second gear **364** in the first gear mode. In examples, a one way clutch **368** can optionally be provided at the second gear **364**. The second gear **364** can be selectively coupled for rotation with a second drive shaft **370**. A second gear set **380** includes first gear **382** selectively coupled for rotation with the first drive shaft **358**. A second gear **384** is coupled for rotation with the second drive shaft **270**. A MAM **386** can include a first disk **420** and a second disk **430** (FIG. 6) that selectively engage to couple for rotation an input **422** (the first drive shaft **358**) with an output **432** (the first gear **382** of the second gear set **280**).

[0030] The drive module **310** can operate in a first gear using a torque path **392** that flows through the first gear set **360**. By way of example only the first gear set **360** can provide a gear ratio of 2.63. Other ratios are contemplated. The drive module **310** can operate in a second gear mode using a torque path **394** that flows through the second gear set **380**. A shift from the first torque path **392** to the second torque path **394** can result in activation (such as from a signal from the controller **130** indicative of a shift request) of the MAM **386**.

[0031] When the first and second disks **420** and **430** move from a disengaged position to an engaged position (again “engaged” can mean a limited slip condition where less than 100% of torque is communicated from input to output), the first drive shaft **358** is fixed or substantially

fixed for rotation with the first gear **382** of the second gear set **380**. In other words, the first and second disks **420** and **430** may not physically touch each other. Instead, the magnetic fluid **410**, when activated, causes the first and second disks **420** and **430** to become at least partially rotatably fixed.

[0032] The first gear **382** in turn rotates the second gear **384** of the second gear set **380**. By way of example only the second gear set **380** can provide a gear ratio of 1.25. Other ratios are contemplated. In examples, the clutch **368** can also be activated thereby eliminating a torque transfer from the first gear **362** of the first gear set **360** to the second drive shaft **370**. Instead, the drive shaft **370** is driven by the second gear set **380** including the first and second gears **382** and **384**.

[0033] With particular reference to FIG. 4, the MAM **386** is shown having magnetic liquid **410** therein. Activation of the magnetic liquid **410** resulting from a signal from the controller **130** causes a torque input **412** to go from a torque output **414** of zero, to a torque output **416** of near 100%. As shown in the plot **418** of FIG. 5, the torque output is linear based on activation moving the MAM **386** from a disengaged to engaged position very quickly and smoothly. In some examples a gear shift can occur in around 0.5 seconds.

[0034] Returning to FIG. 6, the amount of limited slip is controlled by the controller **130** and predetermined by acceptable vibration levels. In other words, the controller **130** determines an amount of limited slip (less than 100% torque transmitted from the input **422** to the output **432** while the first and second disks **420** and **430** at least partially slip) based on a predetermined acceptable vibration level. The predetermined acceptable vibration level can be a predetermined slip value according to a lookup table, or can be an active sensor where vibrations are measured and the controller **130** responsively reacts to increase slip between the disks **420** and **430** to reduce vibrations in the system. The reduction in torsional vibrations provided by the MAM **410** can be experienced by a driver making the driving experience smoother and more desirable. The amount of limited slip condition controlled by the controller **130** facilitates the reduction in NVH.

[0035] It will be appreciated that the term “controller” or “module” as used herein refers to any suitable control device or set of multiple control devices that is/are configured to perform at least a portion of the techniques of the present disclosure. Non-limiting examples include an application-specific integrated circuit (ASIC), one or more processors and a non-transitory memory having instructions stored thereon that, when executed by the one or more processors, cause the controller to perform a set of operations corresponding to at least a portion of the techniques of the present disclosure. The one or more processors could be either a single processor or two or more processors operating in a parallel or distributed architecture.

[0036] It will be understood that the mixing and matching of features, elements, methodologies, systems and/or functions between various examples may be expressly contemplated herein so that one skilled in the art will appreciate from the present teachings that features, elements, systems and/or functions of one example may be incorporated into another example as appropriate, unless described otherwise above. It will also be understood that the description, including disclosed examples and drawings, is merely exemplary in nature intended for purposes of illustration only and is not intended to limit the scope of the present application, its application or uses. Thus, variations that do not depart from the gist of the present application are intended to be within the scope of the present application.

## Claims

1. An electric drive module for an electrified vehicle, the electric drive module comprising: an electric motor having a rotatable output; a transmission that is driven by the rotatable output and includes a first drive shaft and a second drive shaft, the transmission having a first gear set that selectively converts rotatable motion of the first drive shaft into rotatable motion of the second

drive shaft in a first gear mode at a first drive ratio, and a second gear set that selectively converts rotatable motion of the first drive shaft into rotatable motion of the second drive shaft in a second gear mode at a second drive ratio, distinct from the first drive ratio; a multispeed actuation mechanism (MAM) having magnetic fluid therein wherein activation of the magnetic fluid causes selective rotatable communication between the first and second drive shafts; and a controller that commands activation of the MAM whereby a limited slip condition occurs between the first and second drive shafts thereby mitigating vibrations in the electric drive module.

2. The electric drive module of claim 1, wherein the controller commands a predetermined amount of activation of the MAM corresponding to a predetermined acceptable level of vibrations.
3. The electric drive module of claim 1, wherein the controller commands activation of the MAM thereby reducing torque fluctuations within the electric drive module.
4. The electronic drive module of claim 1, wherein the magnetic fluid includes ferromagnetic nanoparticles suspended therein.
5. The electronic drive module of claim 1, wherein the MAM is configured to receive an activation signal from the controller based on sensor inputs of the electrified vehicle indicative of a shift change request.
6. The electronic drive module of claim 1, wherein the MAM further comprises: a first disk; and a second disk, wherein activation of the magnetic fluid results in the first and second disks moving from a disengaged position to an at least partially engaged position.
7. The electronic drive module of claim 6, wherein the first gear set comprises a first gear configured to rotate with the first drive shaft and a second gear that is configured to selectively drive the second drive shaft in a first gear mode.
8. The electronic drive module of claim 7, wherein the second gear set comprises a first gear configured to rotate with the first drive shaft and a second gear that is configured to selectively rotate with the second drive shaft in a second gear mode.
9. The electronic drive module of claim 8, wherein the first and second disks at least partially engage to couple for rotation the first drive shaft with the first gear of the second gear set.
10. The electronic drive module of claim 1, wherein the second drive shaft is rotatably coupled to drive axles that drive respective drive wheels through a differential.
11. An electric drive module for an electrified vehicle, the electric drive module comprising: a transmission that is driven by an output of an electric motor and includes a first drive shaft and a second drive shaft, the transmission having a first gear set that selectively converts rotatable motion of the first drive shaft into rotatable motion of the second drive shaft in a first gear mode at a first drive ratio, and a second gear set that selectively converts rotatable motion of the first drive shaft into rotatable motion of the second drive shaft in a second gear mode at a second drive ratio, distinct from the first drive ratio; and a multispeed actuation mechanism (MAM) having a first disk rotatably coupled to an input shaft and a second disk rotatably coupled to an output shaft, wherein the MAM includes magnetic fluid therein wherein activation of the magnetic fluid causes the first and second disks to at least partially rotate concurrently whereby a limited slip condition occurs between the first and second drive shafts thereby mitigating vibrations in the electric drive module.
12. The electronic drive module of claim 11, wherein the magnetic fluid includes ferromagnetic nanoparticles suspended therein.
13. The electronic drive module of claim 11, wherein the MAM is configured to receive an activation signal from a controller based on sensor inputs of the electrified vehicle indicative of a limited slip change request.
14. The electronic drive module of claim 13, wherein the first gear set comprises a first gear configured to rotate with the first drive shaft and a second gear that is configured to selectively drive the second drive shaft in a first gear mode.
15. The electronic drive module of claim 14, wherein the second gear set comprises a first gear configured to rotate with the first drive shaft and a second gear that is configured to selectively

rotate with the second drive shaft in a second gear mode.

**16.** The electronic drive module of claim 15, wherein the first and second disks at least partially engage to couple for rotation the first drive shaft with the first gear of the second gear set.

**17.** The electronic drive module of claim 16, wherein the second drive shaft is rotatably coupled to drive axles that drive respective drive wheels through a differential.

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