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GB 2476676 A
WO 1998/040647 A1
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Other: **EPODOC, WPI, TXTA**

(54) Title of the Invention: **Kinetic energy recovery system**
Abstract Title: **Kinetic energy recovery system transmission and drivetrain**

(57) A transmission is provided for a vehicle mechanical kinetic energy recovery system 24 (MKERS) comprising three ratio sets in series (see figs 5 & 6), each ratio set comprising at least two selectable ratios connected in parallel with one another, at least one of the ratio sets comprising friction clutches. The transmission comprises an input that is caused to rotate at a speed proportional to the road-speed of the vehicle. Kinetic energy is typically stored in a flywheel (F see fig 4). The invention seeks to provide a large range of selectable gear ratios which may be usable when the flywheel is storing energy to providing torque. 8 speed and 9 speed versions of the transmission are provided.

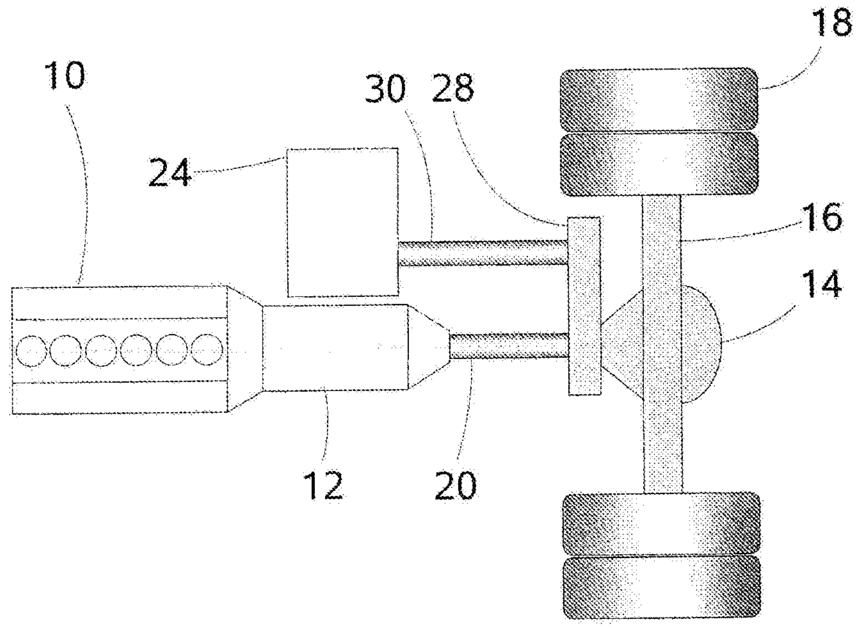

Fig 2

GB 2528166 A

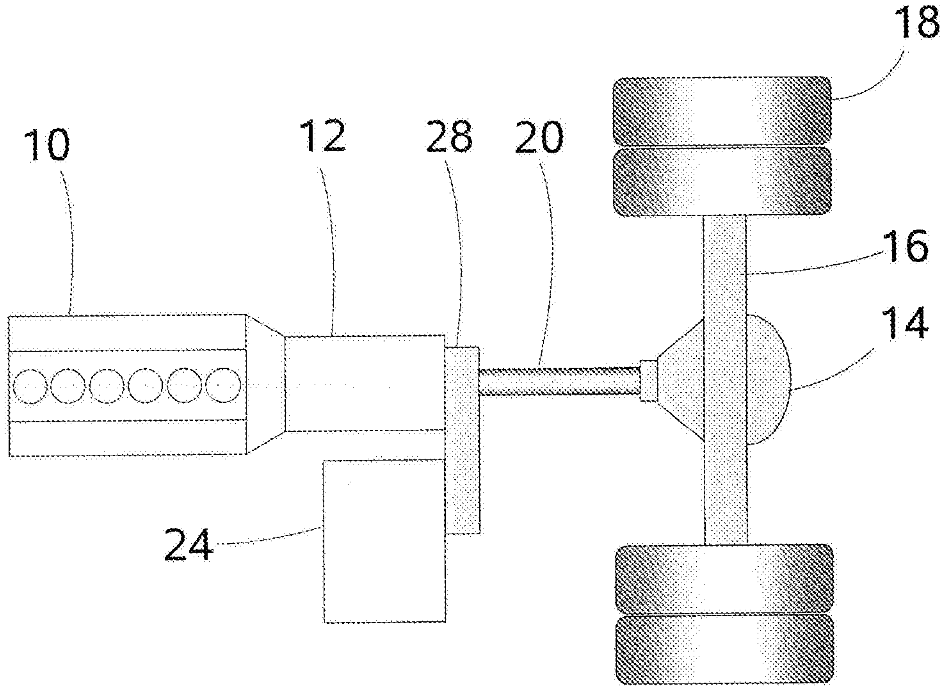

Fig 1

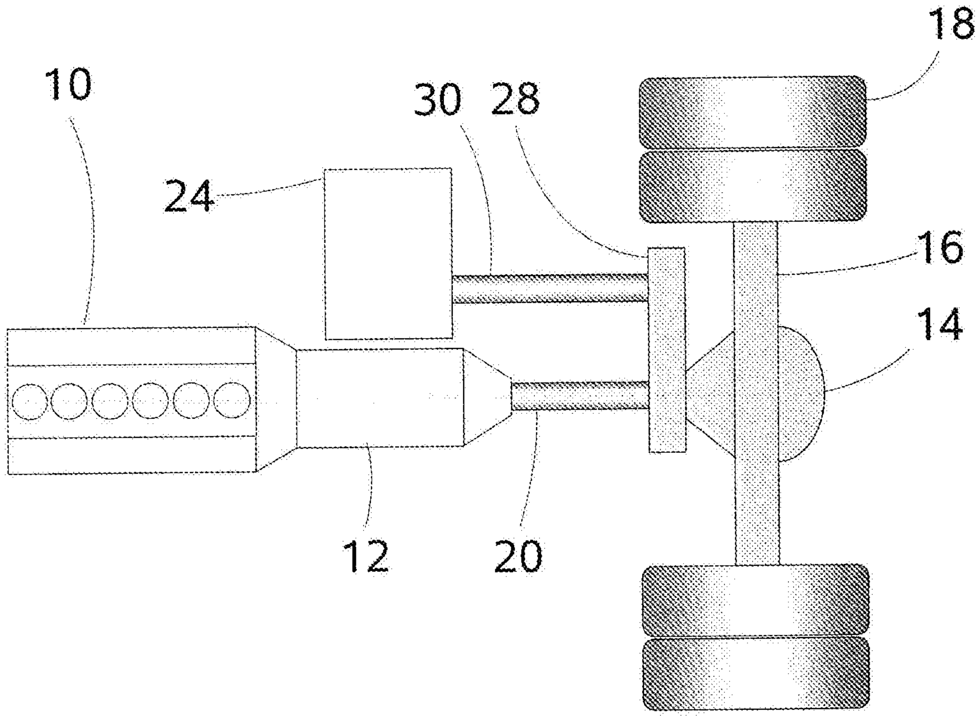

Fig 2

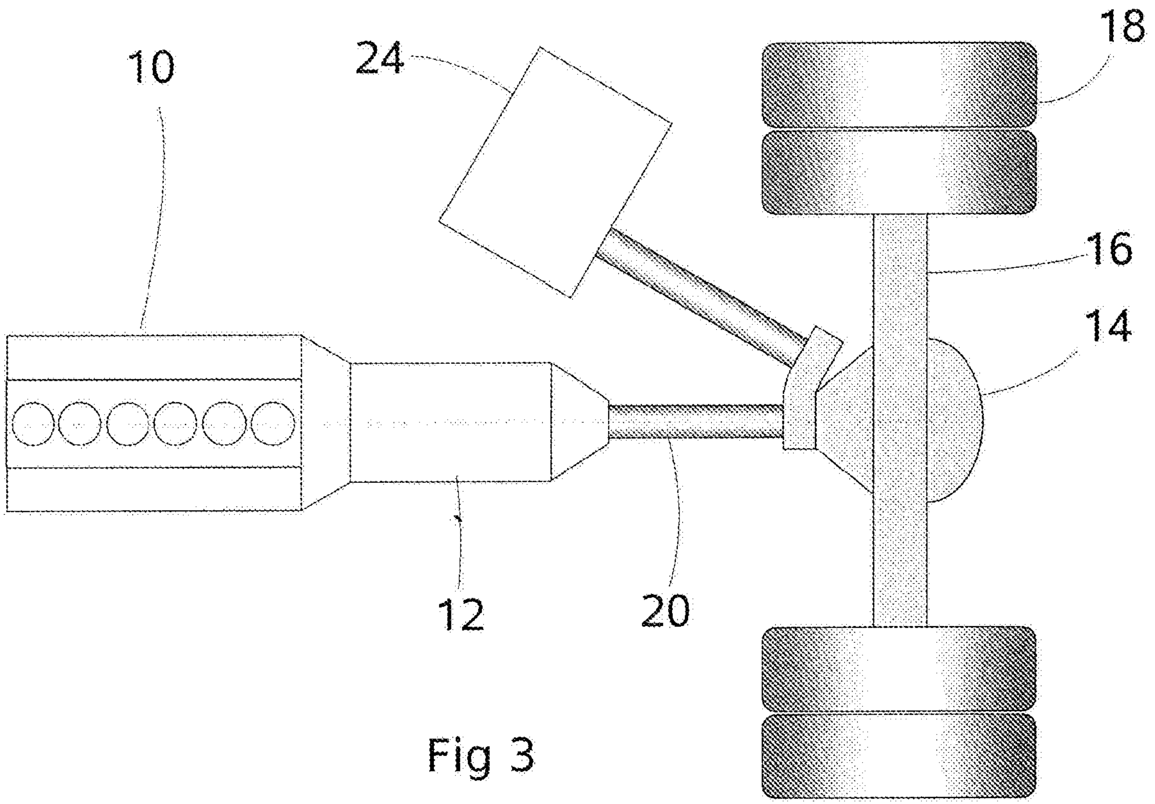

Fig 3

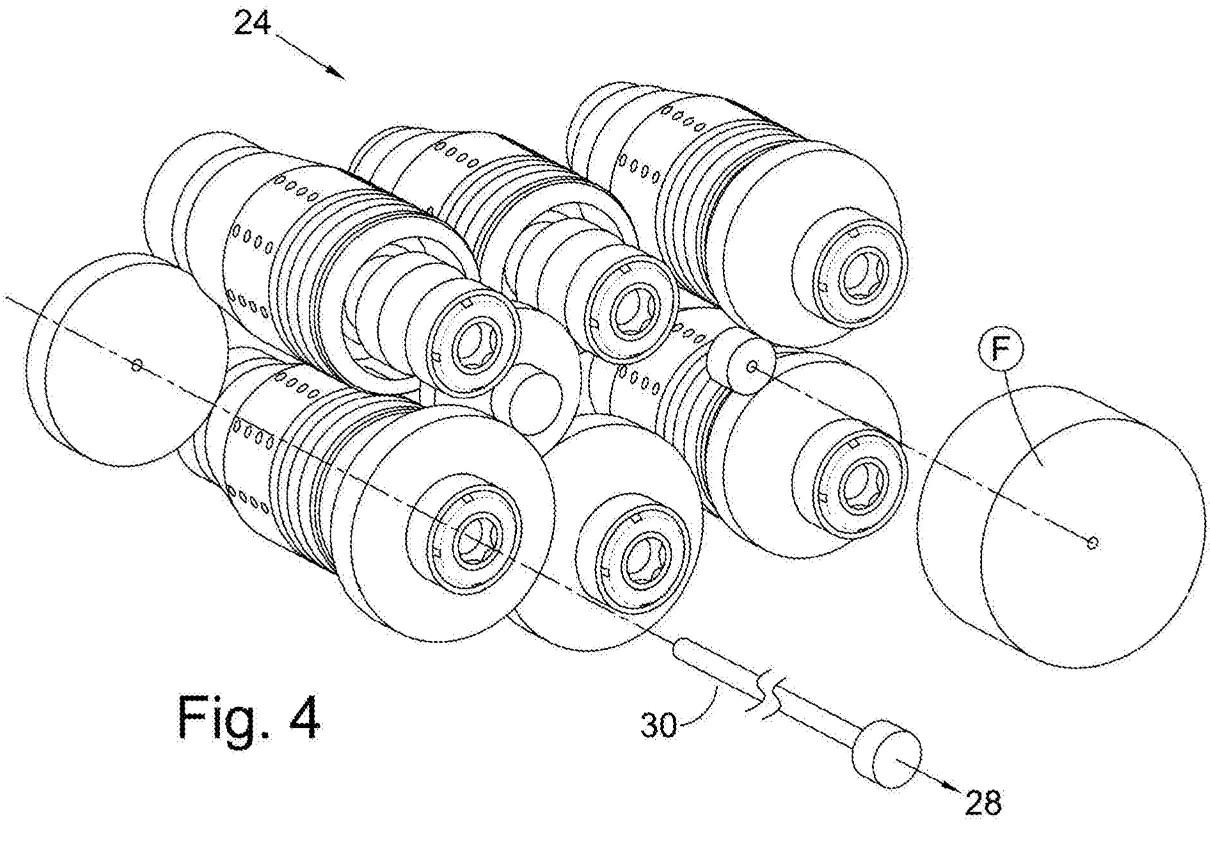

Fig. 4

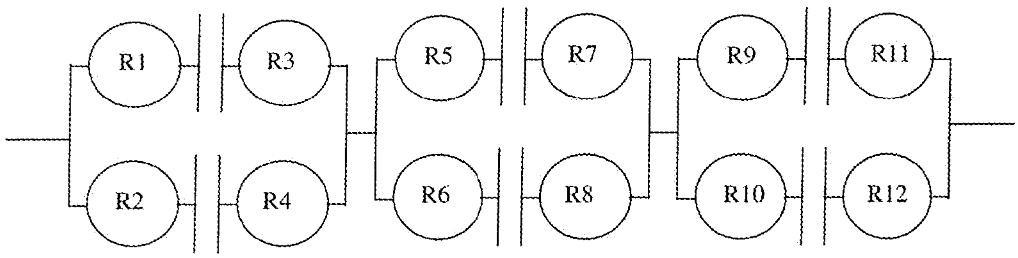
R1
R3
R5
R7
R9
R11
R2
R4
R6
R8
R10
R12

Fig 5

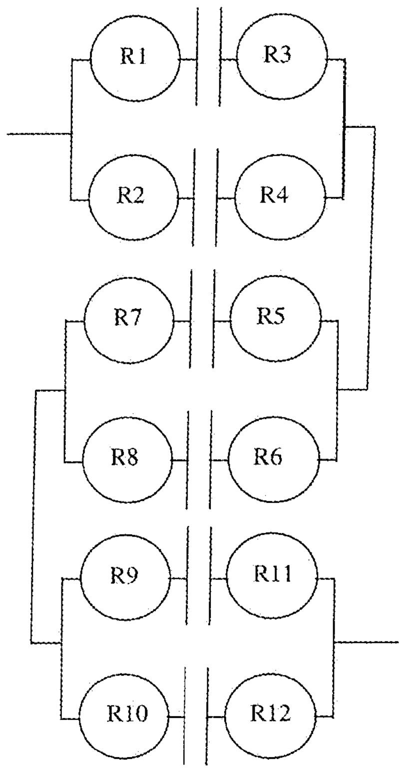
R1
R3
R2
R4
R7
R5
R8
R6
R9
R11
R10
R12

Fig 6

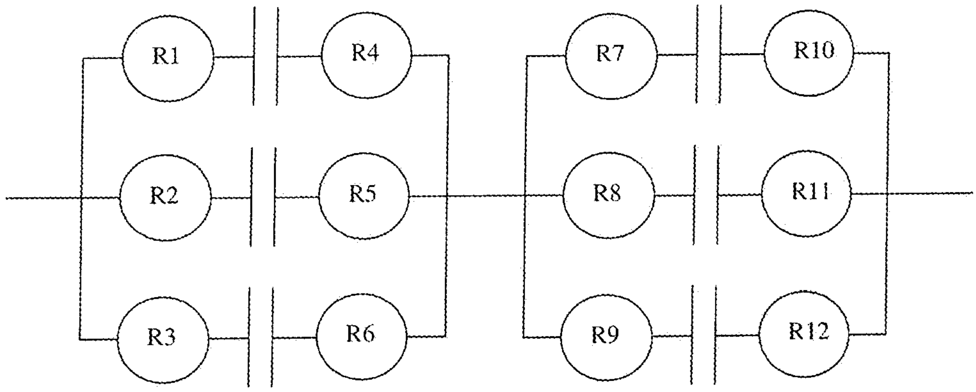
R1
R4
R7
R10
R2
R5
R8
R11
R3
R6
R9
R12

Fig 7

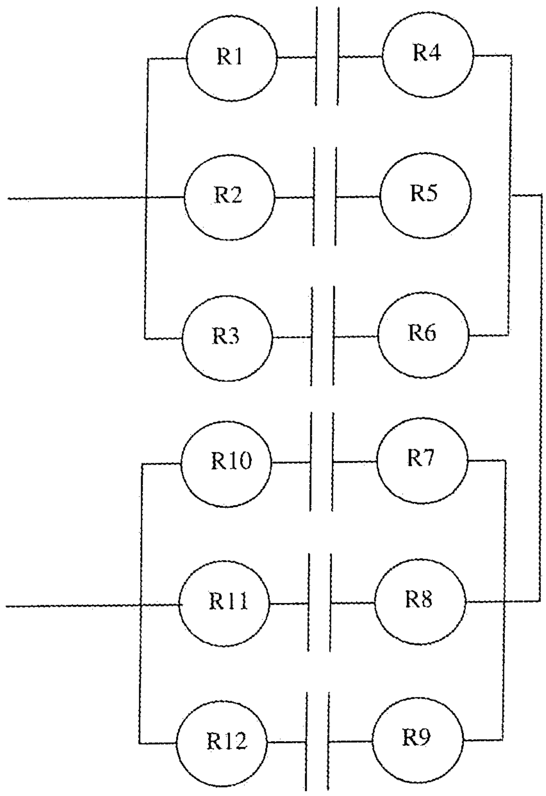
R1
R4
R2
R5
R3
R6
R10
R7
R11
R8
R12
R9

Fig 8

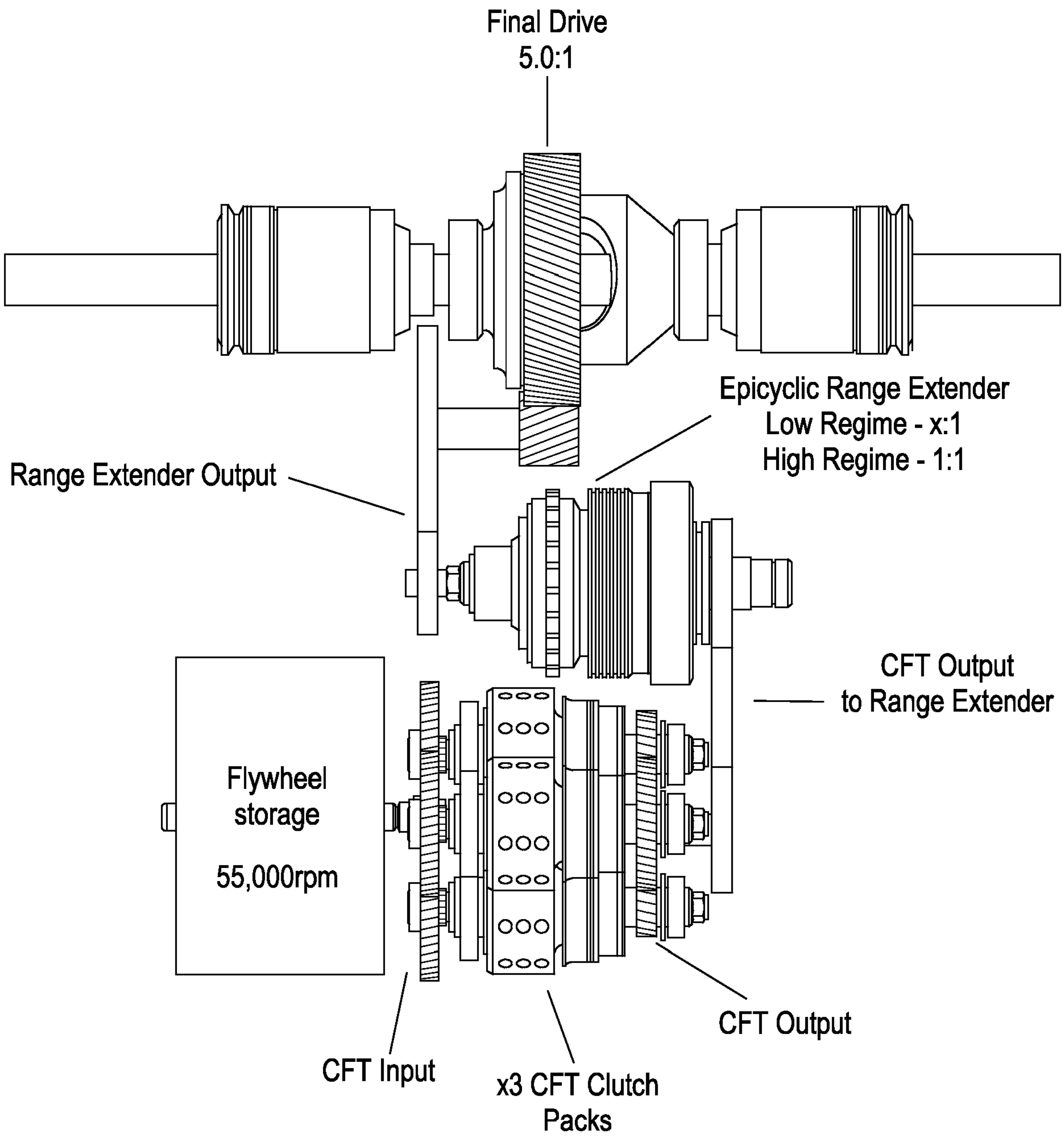
Final Drive
5.0:1
Epicyclic Range Extender
Low Regime - x:1
High Regime - 1:1
Range Extender Output
CFT Output
to Range Extender
Flywheel
storage
55,000rpm
CFT Output
CFT Input
x3 CFT Clutch
Packs

Fig. 9

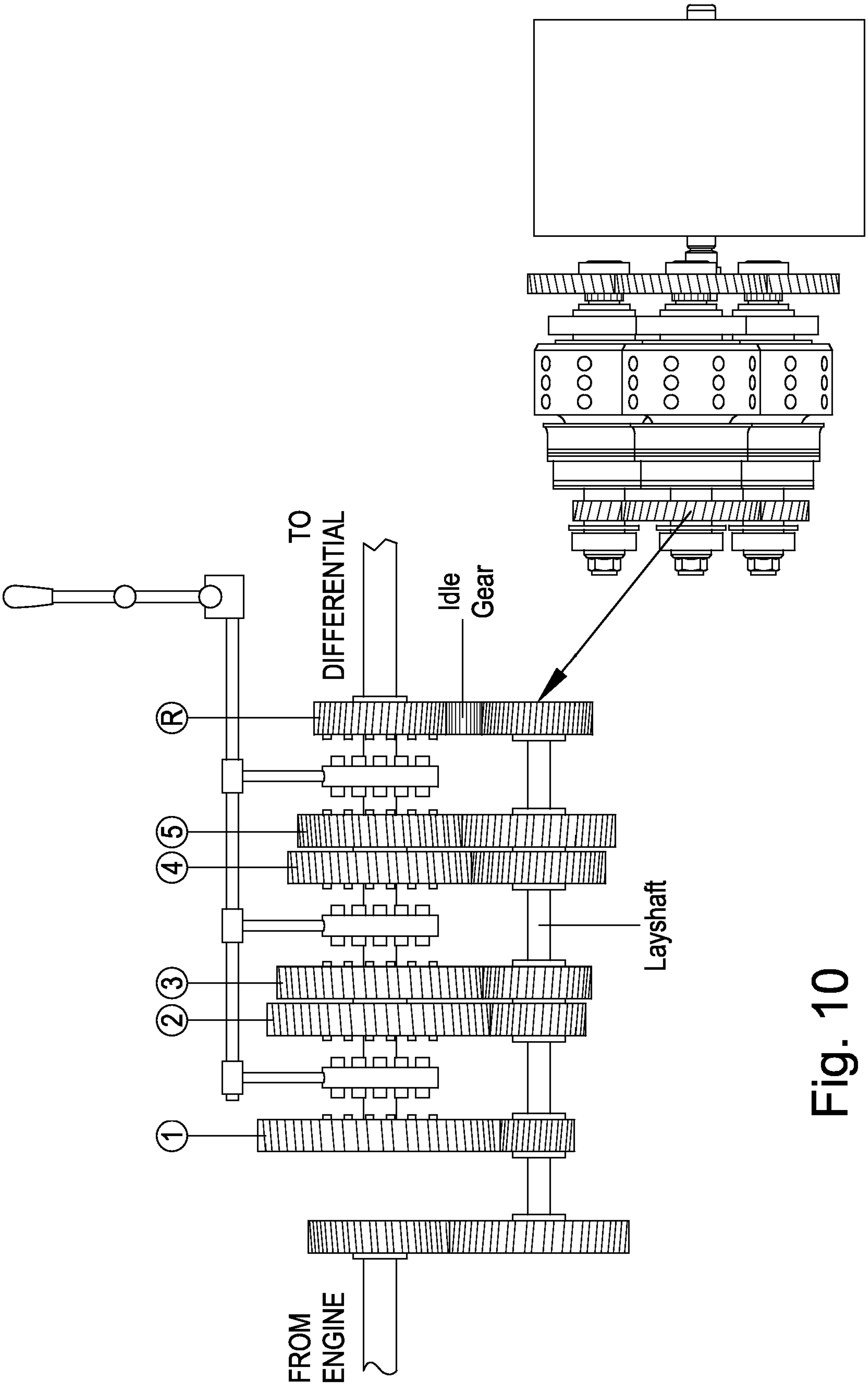

Fig. 10

Kinetic Energy Recovery System

The present invention relates to a kinetic energy recovery system. In particular, it relates to a kinetic energy recovery system in which energy is stored as rotational kinetic energy in a flywheel, and has particular, but not exclusive, application to a main drive of a vehicle. The abbreviation “MKERS” will be used to refer to a mechanical kinetic energy recovery system.

It is known to attach an MKERS at various parts of a vehicle drivetrain: at the engine, on the turbine side of the torque converter (if the main drive transmission is an AT), or on a power take off (which may be located either on the engine or on the turbine side of the torque converter). In each of these arrangements, an input to the MKERS turns at a speed that is directly related to the engine speed. It is also known to connect an MKERS to the transmission output (transmission side of the prop-shaft) or on the rear axle itself. In each of these latter arrangements, an input to the MKERS turns at a speed that is directly related to the vehicle road speed.

The MKERS comprises typically a flywheel system and a transmission for transmitting power to and from a power sink/source, this sink/source typically being the wheels of the vehicle (although the sink/source may equally be the prime mover such as an electric motor or internal combustion engine). The significance of the sink/source is that power flow transmitted to or from the flywheel may be in either direction. The transmission is required to accommodate a continuously varying ratio between the flywheel and the power source/sink as the speed of at least the flywheel and potentially both the flywheel and the power source/sink varies continuously as power is exchanged between the two. Typically, power flow *to* the flywheel causes the flywheel to accelerate thus increasing its speed whilst (in this case) the sink/source acts as a source and is decelerated. Thus, power flow to the flywheel causes the source/sink to decelerate; examples of this event include vehicle regenerative braking. Conversely, power flow *from* the flywheel causes the flywheel to decelerate thus decreasing its speed whilst, in this case, the sink/source acts as a sink is accelerated; accordingly, power flow from the flywheel causes the source/sink to accelerate; examples of this event include vehicle regenerative acceleration. The case whereby the power source/sink is a vehicle will be used in the following description.

The flywheel energy capacity is related to the square of its speed which means that in order to utilise the bulk of its energy capacity (say, 90%), it is preferable that 70% of its speed range (that is, operating from 30% of maximum operating speed to the maximum flywheel operating speed) should be used. Similarly, the kinetic energy of the vehicle is related to the square of its speed, therefore 90% of its maximum energy (which may, through regenerative braking, be recycled by passing it via the MKERS transmission to/from the flywheel) is stored in the 70% of its speed range. Thus the flywheel, and the vehicle, may each be required to operate with a ratio of maximum speed to minimum speed equal to or greater than approximately 3.4 (i.e. approximately 100/30). In order to harvest the bulk of the vehicle's energy, and in order to minimise the flywheel size and cost by utilising the bulk of the flywheel energy storage capacity, it may be seen that the ratio spread (that is, the maximum ratio divided by the minimum ratio) of the MKERS must therefore be 3.4^2 (approximately 11) or greater. Given that most automatic transmissions for main vehicle drives feature a ratio spread of between 6 and 8, creating the preferable ratio range for optimum energy recovery in MKERS can present a challenge.

One way to address this challenge is to position the MKERS on the engine-side of a vehicle transmission such that the ratio range between vehicle speed and flywheel are multiplied up by the range of the main vehicle transmission. This is especially important in the case where the medium of variable speed is a slipping clutch rather than a variable ratio CVT as the ratio spread and efficiency of the CFT are related to the maximum percentage slip of the slipping clutch; the efficiency decreases with increasing slip, and the mean slip of the device across its operating range relates to mean efficiency.

GB-A-2 476 676 describes a compact, 3-speed clutch arrangement (termed Clutched Flywheel Transmission (CFT) or variable slip transmission (VST)) that dispenses with the cost and complexity of a CVT by solely using slipping clutches as the medium of power transfer to and from the flywheel. However, to achieve adequate efficiency, such a device must be connected to the input side of a vehicle transmission to make use of the range of the main transmission.

There are advantages in component packaging, adaptation and others to be achieved by positioning an MKERS on the transmission output, axle or in any case, on the wheel side of the main drive transmission. However, the device of GB-A-2476676 is not suited for use in such a position.

From a first aspect, this invention provides a drivetrain for a vehicle that comprises an engine, a variable speed main drive transmission, a final drive having an input coupled to an output of the variable speed transmission, a mechanical kinetic energy recovery system (MKERS), in which the kinetic energy recovery system is operatively coupled to the drivetrain:

- such that it has an input that is caused to rotate at a speed proportional to the road-speed of the vehicle; and/or

- such that it has an input that is caused to rotate at a speed proportional to the output of the variable speed transmission and/or the input of the final drive; and/or

- at an output of the variable-speed transmission; and/or

- at the final drive; and/or

- between the variable-speed transmission and the final drive.

The MKERS includes a variable speed drive between an input and a flywheel. The variable-speed drive includes one or more clutches that can operate in a slipping mode. Clutches may also operate in a non-driving (open) mode.

From another aspect, this invention provides for a transmission for a kinetic energy recovery system according to the first aspect of the invention.

From another aspect, this invention provides for a transmission for a kinetic energy recovery system comprising a flywheel, a first ratio set comprising a plurality of clutches arranged in parallel and for operation in a slipping mode for the control and transmission of power to or from the flywheel, and a second ratio set comprising a plurality of selectable ratios each in parallel with one another, arranged in series with the first ratio set.

The use of clutches for the transmission of power can reduce cost and complexity of a final product. Extending the ratio range afforded by the first clutch set alone by adding a second clutch set arrange in series increases the opportunity for energy capture and efficiency by increasing the overall ratio range of the MKERS transmission, and/or reducing the percentage slip across the slipping clutches, for a given ratio range.

The KERS transmission may alternatively be caused to rotate at a speed proportional to the engine-speed of the vehicle, for example the input to the KERS transmission may be coupled to the input or output of a torque convertor, to the engine crankshaft, or to the layshaft of a manual gearbox. Incorporation of two ratio sets in series increases the total number of ratios which in turn advantageously increases one or both of the ratio spread of the KERS transmission and/or its mean efficiency, as previously described. Typical embodiments may incorporate a three speed clutched flywheel transmission (this being the first ratio set) in series with a two speed clutched range extender, this being the second ratio set, thus providing six KERS transmission speeds. The additional speeds available in the main drive transmission provides greatly enhances mean 'round trip' efficiency (that is, the total efficiency of energy transfer when energy flows from the wheels to the flywheel, and back to the wheels). For example, if a vehicle has a main drive transmission with six speeds then there are a total of thirty six speeds in the path between wheels and flywheel in this example (six KERS speeds multiplied by six main drive transmission speeds). Thus a KERS with a range-extended CFT may offer certain efficiency and thus fuel economy (and/or performance enhancement) advantages over a non-range extended version when mounted on the engine side of a main drive transmission.

Although the second clutch set may be of a meshing variety (for instance, dog clutches or crash gears), it preferably comprises friction clutches as this can offer advantages of commonality (or re-use) of existing part types used in the first clutch set, and actuation by a common hydraulic power source together with the first clutch set.

In other preferred embodiments, the clutches may be wet clutches that are advantageously cooled by oil. The oil may serve both as a lubricant and a coolant, whereby heat generated by the combination of torque reaction and slip speed may be taken away through convection by cooling oil. Cooling oil may be fed to an inner radius of the clutch inner radii, and thrown e.g., by centrifugal action to the outer radius as the clutch rotates.

Considering the first clutch set alone, one disadvantage of using clutches is the drag created due to differential speeds across the clutch, this being exacerbated potentially by the high magnitude of speed generally required in a high speed flywheel transmission and also by the considerable cooling oil flow fed continuously to the clutch pack. Accordingly, in a second aspect the invention provides an energy recovery transmission comprising a flywheel, and plurality of clutches arranged in parallel and for operation in a slipping mode for the control and transmission of power to or from the flywheel, and means for supplying to the clutches a rate of oil flow that is a function of the magnitude of power transmitted to or from the flywheel.

Preferably oil is fed to the clutches when there is power transfer through the clutches, and oil is not fed to the clutches when power flow is near to or at zero. The oil flow rate may be activated by electrical or electro-mechanical means such as a solenoid valve which may be controlled by an Electronic Control Unit (ECU) of the MKERS or in a preferred embodiment it may be activated hydro-mechanically by piloting a valve that allows lubrication to a clutch when pressure is fed to or sensed in its clutch piston cylinder.

Clutch oil may also be fed to the gears in the transmission, and preferably should be fed to the portion of the gear or gears as they exit the mesh, as this is the hottest point of the gear and therefore the point at which cooling will be most effective, advantageously requiring a lower quantity of cooling oil.

This invention also provides a transmission for a vehicle mechanical kinetic energy recovery system (MKERS) comprising three ratio sets arranged in series, each ratio set comprising at least two selectable ratios connected in parallel with one another, wherein all ratios of one of the ratio sets are selectable by friction clutches. Preferably all of the ratio sets each comprise at least two clutches (and preferably two and only two clutches), thus yielding at least 8 possible combinations of KERS ratios. It may be shown that eight ratios offer an efficiency almost as high as nine ratios of a “3x3” configuration (two ratio sets in series, each ratio set comprising three selectable ratios connected in parallel), but with considerable packaging advantages. The MKERS transmission may comprise an input that is caused to rotate at a speed proportional to the road-speed of the vehicle. The MKERS transmission may be coupled to a final drive of the vehicle. It may alternatively be coupled via a driveshaft to a transfer box connected to the output of the transmission (similar to the transfer box arrangement shown in Figure 1), in which case the said driveshaft may be connected to the transfer box via a right-angled coupling such as a bevel gear arrangement that allows the driveshaft to extend laterally away from the longitudinal axis (i.e. the centreline) of the vehicle in a direction that is substantially perpendicular or near-perpendicular to the vehicle longitudinal axis. In such an embodiment the MKERS and drive-shaft may be similar to the arrangement shown in Figure 4, and the MKERS may be positioned towards the side of the vehicle. Preferably it is coupled to a final drive of the vehicle by a drive-shaft. All selectable ratios of the MKERS transmission preferably comprise friction clutches, enabling each ratio to be switched or selected at will, even if torque is borne by the clutch when it is switched. Each respective clutch may form part of a clutch assembly and at least two of the clutch assemblies may preferably be the same, thus leveraging economies of scale in manufacture, and enabling a lower cost MKERS. Each ratio set of the MKERS may be arranged laterally of one another with respect to the longitudinal central axis of the vehicle. Thus the ratio sets may be positioned alongside each other in a compact configuration suited to installation in a vehicle, for example in a bus in which there is typically limited space to the side of the main drive gearbox at the rear of the vehicle. Each clutch may rotate about a clutch axis, and preferably the rotational axes of all clutches in the MKERS are substantially parallel to one another. The axes may also be substantially parallel to the longitudinal axis of the vehicle. Multiple ratio sets may enable a wide ratio spread, which in turn may enable increased opportunity for energy capture and hence enhanced fuel economy. In a transmission with slipping clutches, which may tend to be slightly less efficient than a transmission that includes a CVT, preferably the transmission has a ratio spread (that is, the absolute maximum ratio divided by the absolute minimum ratio) of 11 or greater, thus enabling the transmission to match the efficiency of a CVT even when coupled to the final drive of a vehicle. As described earlier, one clutch of the transmission may serve as a drive disconnect, allowing the MKERS to be decoupled from the vehicle drive. The plurality of clutches of the MKERS transmission may be arranged for operation in a slipping mode for the control and transmission of power to or from the flywheel, and may comprise means for supplying to the clutches a rate of oil flow that is a function of the magnitude of power transmitted to or from the flywheel. Advantageously the supply of oil may be cut or reduced when power is not being transmitted, thus reducing drag of the high speed flywheel transmission when it is not in use.

The transmission may also include a controller that controls at least one of the clutches in a substantially continuously slipping mode throughout the duration of torque transfer through the (MKERS) transmission.

The transmission preferably includes a high-speed flywheel. Such a flywheel may be arranged to rotate at speeds of the order of 15,000 rpm or greater. Preferably, such a flywheel may be arranged to rotate at speeds of the order of 20,000 rpm or greater. Preferably, such a flywheel may be arranged to rotate at speeds of the order of 25,000 rpm or greater. Preferably, such a flywheel may be arranged to rotate at speeds of the order of 30,000 rpm or greater. Preferably, such a flywheel may be arranged to rotate at speeds of the order of 60,000 rpm.

This invention also provides a drivetrain for a vehicle that comprises an engine, a variable speed main drive transmission, a final drive having an input coupled to an output of the variable speed transmission, a mechanical kinetic energy recovery system (MKERS) including a variable speed drive coupled between an input and a flywheel of the MKERS, the input to the MKERS being operatively coupled to the drivetrain such that it is caused to rotate at a speed proportional to the road-speed of the vehicle, wherein the MKERS comprises three ratio sets in series, each of the ratio sets comprising at least two clutches each with an associated ratio, each clutch and associated ratio connected in parallel with its other clutch and associated ratio of the same set, wherein the clutches of one of the ratio sets can operate in a substantially continuously slipping mode and in a non-driving (open) mode.

The drivetrain may include a transmission according to any other aspect of this invention.

Embodiments of the invention will now be described in detail, by way of example, with reference to the accompanying drawings, in which:

Figure 1 shows a drivetrain of a vehicle that includes an MKERS operatively coupled to an output of a main drive transmission;

Figure 2 shows a drivetrain of a vehicle that includes an MKERS operatively coupled to an input of a final drive transmission;

Figure 3 shows a drivetrain of a vehicle that includes an MKERS operatively coupled to an input of a final drive transmission being an alternative packaging arrangement to that of Figure 2;

Figure 4 shows a possible layout of gearsets and clutches in an embodiment of the invention from Figure 2 that is a three twin-clutch ('2x2x2') configuration;

Figure 5 is a stick diagram of a serial twin-clutch configuration (2x2x2 = 8 speed);

Figure 6 is a stick diagram of an alternative layout of a serial twin-clutch configuration (2x2x2 = 8 speed);

Figure 7 is a stick diagram of a serial triple-clutch configuration (3x3 = 9 speed);

Figure 8 is a stick diagram of an alternative layout of a serial triple-clutch configuration (3x3 = 9 speed);

Figure 9 shows a rear wheel drive (rear axle) KERS; and

Figure 10 shows a manual transmission in which a three speed CFT (KERS transmission) is connectable to the layshaft of a manual gearbox for rotation at a speed related closely to engine speed.

With reference to Figures 1 to 3, three alternative drivetrain layouts are shown. These are essentially the same in function, and differ only in the layout of components within the vehicle. Such drivetrains may find application, for example, in a single-deck passenger bus, in which case, the engine is typically at the rear of the vehicle behind the axle.

Each drivetrain comprises an engine 10, a variable speed main-drive transmission 12 (for example, a multi-speed automatic gearbox), a final drive 14 on an axle 16 that carries driven road wheels 18 and a propshaft 20 that connects the transmission 12 to the final drive 14. The drivetrain further includes an MKERS 24 unit. The engine 10, main-drive transmission 12 and the propshaft 20 are disposed longitudinally straddling a centre line (that is, the longitudinal axis) of the vehicle.

In the embodiment of Figure 1, the drivetrain further includes a transfer unit 28 carried on an output of the main-drive transmission 12. The transfer unit 28 transmits drive transversely of the centre line such that the KERS unit 24 is displaced from the centre line adjacent to the transmission 12.

In the embodiment of Figure 2, the drivetrain includes a transfer unit 28 carried on an input to the final drive 14. A drive shaft 30 extends from the transfer unit 28 rearwardly and approximately parallel to the vehicle centre-line to the KERS unit 24, which can be mounted, for example, adjacent to the transmission 12.

In the embodiment of Figure 3, the drivetrain includes a transfer unit 28 carried on an input to the final drive 14. A drive shaft 30 extends from the transfer unit 28 rearwardly at an acute angle to the vehicle centre line to the KERS unit 24, which can be mounted, for example, adjacent to the transmission 12 and offset to the centre line.

In the embodiment of Figure 4, the '2x2x2' configuration is shown, in which the drive-shaft (preferably a prop-shaft) 30 couples the MKERS transmission to the transfer box 28. In this configuration, the transfer box is preferably coupled to the final drive unit 14 (e.g. as shown in Figure 2). This MKERS configuration comprises three sets of selectable ratios. Each set comprises an intermediate input gear, and an intermediate output gear, each of the intermediate gears meshing with and driving a pair of input gears and output gears of a ratio set respectively. Each input gear has a facing output gear with a clutch between, each input gear, output gear and associated clutch being mounted for rotation about a common axis. Thus each ratio set has two clutches each with an associated gear ratio, and each clutch and its associated ratio is arranged to be in parallel with the other clutch and associated ratio of the same set, and each of the gear ratios of the set is therefore selectable. In this example each ratio set comprises two ratios each of which is selectable by a friction clutch, although more or fewer than two may be used.

The drive-shaft 30 extends from the transfer box 28 and connects to a gearwheel of the MKERS transmission that is rearward-most with respect to the vehicle. This gearwheel serves as the intermediate (or driving) gear of the first ratio set. The first ratio set then extends rearwardly from this gearwheel. The output intermediate gear of the first ratio set is a double gearwheel that engages with both the output gears of the first ratio set, and with the input gears of the second ratio set. The double gearwheel therefore serves both as the output intermediate gear of the first ratio set and the input intermediate gear of the second ratio set. The second ratio set is arranged laterally of the first ratio set with respect to the centre line (that is, the longitudinal axis) of the vehicle. It is farther from the centreline of the vehicle than the first ratio set. The output intermediate gear of the second ratio set is once again towards the rearward-most region of the MKERS, and this engages with the input gears of the third ratio set which is, again, positioned laterally of the second ratio set with respect to the centre line (that is, the longitudinal axis) of the vehicle. The third ratio set is farther from the centreline of the vehicle than the second ratio set. The output intermediate gear of the third ratio set is in a forwardly portion of the MKERS, and engages with a pinion gear which is coupled to the high speed flywheel 'F'. The pinion gear provides a large step-up in the speed of the flywheel, thus enabling significant energy to be stored and recovered by the MKERS. The rotational axes of all selectable clutches and gears of the MKERS are parallel with one another. These axes are also parallel with the rotational axis of the flywheel 'F'.

The ratio set which has closely spaced ratios and which serves as the CFT may be nearest the drivetrain, nearest the flywheel, or disposed between the other two ratio sets. Preferably the ratio set closest to the flywheel is the CFT ratio set and is arranged to control power flow to and from the flywheel in a continuously slipping mode. In this way, the most frequent switching is performed by the ratio set that is distant from the drivetrain, thus minimising disturbance to the vehicle wheels. The second ratio set is adjacent to the CFT ratio set and preferably has selectable ratios that are spaced by the square of the ratio spread of the CFT ratio set. Furthermore, the third ratio set that is adjacent to the second ratio set preferably has selectable ratios that are spaced by the square of the ratio spread of the second ratio set. Thus if the CFT ratio set has a ratio spread of R2/R1 then the second ratio set has ratios R1', R2' where $R2'/R1' = (R2/R1)^2$. The third ratio set has ratios R1", R2" where $R2''/R1'' = (R2/R1)^4$. This system may achieve a constant mean efficiency during each slip event of the clutches, as described in the following passage.

Let R1/R2 = 0.74. Consider the starting condition whereby the relative speeds of the flywheel and vehicle are such that the second and third ratio sets' R1' and R1" clutches (respectively) are engaged with zero slip, but such that the percentage slip across the R1 CFT clutch is approximately 26%. The engaged CFT clutch R1 is initially engaged with a controlled torque capacity such that power flows to the flywheel (say). As the flywheel and vehicle speeds change, the slip across R1 approaches zero. Its mean slip has been approximately 13%, so the CFT has achieved a nominal mean efficiency of 87%. The engaged CFT clutch R1 is now disengaged and ratio R2 is engaged with a controlled torque capacity such that power flows to the flywheel. R2 initially slips by 26% but as the flywheel and vehicle speeds change, the slip across R2 approaches zero and a mean efficiency of 87% is once again achieved. At this point, the ‘sweep’ of the CFT (that is, the first) ratio set is complete, and the second ratio set must now be switched. In order to do this, the R1’ clutch is disengaged and the R2’ ratio selected. Simultaneously the R2 clutch is disengaged and the R1 clutch engaged with a controlled torque. Since the spacing of the second ratio set is $(R2/R1)^2$, R1 clutch will now slip by 26% once again. Once the ‘sweep’ of the CFT clutches is complete, the third ratio set switches engagement of R1” to R2” whilst simultaneously the second ratio set switches from R2’ back to R1’ and the CFT ratio switches from slipping R2 (currently in use) back to slipping R1. Thus, it is clear that such sequential switching of the gear sets in the serial ratio sets can make use of all permutations of the available selectable ratios, and that, in this example, the full ratio spread of the MKERS is $1/0.74^8 = 11.1$.

In one embodiment, the invention comprises a cascade of two ratio sets in series, the first comprising at least two [but preferably [at least] three] clutches each connected via a corresponding ratio and the second comprising at least two, but preferably three selectable ratios. Two sets of three ratios provides for nine ratios in total. These may be arranged substantially in geometric progression such that, with 26% maximum slip across each clutch, this offering a mean efficiency of 87%, an overall ratio spread of 0.74 to the power -9 (approximately 15) is possible. This is much higher than the ratio spread of 4-7 offered by a typical a CVT, advantageously maximising the opportunity for energy recovery. Further, the mean efficiency level is similar in magnitude to many CVTs, thus offering a respectable round trip efficiency and providing effective net energy recovery and fuel savings. In this embodiment, a further disconnect clutch may be arranged in series with said two ratio sets for the purpose of adding additional possibilities for the disengagement of the flywheel from the vehicle powertrain. It may be shown that this advantageously adds to the level of functional safety of the system.

In an embodiment there is a cascade of three ratio sets in series, the first comprising at least two clutches each connected via a corresponding ratio, and the second and third each comprising at least two selectable ratios. Three sets of two ratios provides for eight ratios in total, and therefore a similar level of ratio range, opportunity for energy regeneration and mean efficiency as the aforementioned three by three system. Advantageously, the drive disconnect clutch may be eliminated whilst maintaining a similar level of system functional safety. A further advantage is that a greater number of similar clutch set designs may be utilised (i.e. three sets of similar clutch sets (rather than two) per transmission), whilst the total number of clutches remains the same (six clutches) thus leveraging further economies of scale; this further reduces the cost of the system. It may also be shown that this arrangement typically reduces the number of serial gear meshes in the MKERS power path which in turn increases the round-trip efficiency. This advantage may be explained by the fact that this embodiment enables the drive disconnect clutch to be eliminated. Further, two larger serial ratio stages typically offers less natural packaging flexibility and more intermediate gears compared with three compact serial ratio stages.

Figure 9 shows an MKERS transmission for connection to the rear axle of a vehicle. The vehicle may be a front-wheel-drive vehicle, with a conventional powertrain including an engine and main-drive transmission which together provide power to a front drive of the vehicle, and with the MKERS arranged to provide power to a rear drive of the vehicle. Alternatively, the vehicle might be a rear-wheel-drive vehicle, with a conventional powertrain including an engine and a main-drive transmission which together provide power to a rear drive of the vehicle, wherein the MKERS is arranged to also provide power to the rear drive of the vehicle. In other embodiments, these arrangements may be reversed, so that a conventional powertrain and an MKERS provide power to a front drive of the vehicle, or a conventional powertrain provides power to a rear drive of a vehicle and an MKERS provides power to a front drive of the vehicle.

In the illustrated example of Figure 9, a high speed flywheel (for energy storage) is connected to the input of a three-speed clutched flywheel transmission (CFT). The CFT output is connected via transfer gears to a range extender (this being a second ratio set for increasing the number of MKERS selectable ratios and hence the efficiency and/or ratio range of the CFT) which is positioned behind (aft of) the CFT within the vehicle. Further gearing transfers the drive to the crown wheel of a final drive and differential gear which is positioned on the rear axle, the differential allowing equal torques to be applied to each wheel and accommodating cornering, as is well known to those skilled in the technical field. In this example, the range extender includes an epicyclic and two clutches thus providing two ratios (speeds) in series with the CFT; the flywheel has a storage capacity of 210kJ. (Note that the terms ‘input’ and ‘output’ as applied to the CFT and MKERS transmission do not indicate a direction of power flow; the power may flow through the kinetic energy recovery system in either direction). This arrangement offers the advantage that it may be optionally fitted (by a vehicle manufacturer) as a module separately from the front wheel drive conventional powertrain. Fitment may therefore not disrupt the conventional powertrain of the vehicle. Such an arrangement may preferably comprise a second ratio set (or range extender) in series with the CFT.

The flywheel illustrated in Figure 9 is arranged for rotation at speeds of approximately 55,000 rpm. This speed regime may be particularly suitable for use in relatively lightweight road vehicles such as cars. Generally, for lightweight vehicles and/or vehicles that have low duty cycles such as passenger cars, the preferable flywheel maximum operating speed may be 50,000 rpm or greater. A flywheel might alternatively be arranged for rotation at speeds of approximately 25,000 rpm. This speed regime may be particularly suitable for use in heavier vehicles, such as buses or off-road vehicles. Generally, for heavier vehicles and/or vehicles that have arduous duty cycles such as construction vehicles (e.g. loading vehicles or excavators), or material-handling vehicles (e.g. fork-lift trucks or handling vehicles), the preferable flywheel maximum operating speed may be 20,000 rpm or greater.

Figure 10 shows an MKERS that is connectable to or integratable into a manual gearbox. Advantageously the space used by such an integrated unit may be smaller and of lower cost than if a complete MKERS (including separate transmission together with its own housing / casing) were to be installed in the vehicle, for example on a rear axle of a front wheel drive vehicle. The system shown in Figure 10 includes a high speed flywheel that is driven via a step up ratio by the input of a CFT whose output is attached to the layshaft of a manual gearbox (which is the main drive transmission of this vehicle) that, in this example, has five forward speeds and one reverse speed. Gears are selected by movement of a user-actuated gear lever that connects to shift-forks, these in turn shifting mechanisms that both synchronise and engage with the selected gear (as will be well known to those skilled in this technical field). By positioning the CFT output on the main drive transmission layshaft, the CFT output may rotate at engine speed. Advantageously the round trip efficiency between wheels and flywheel is increased through utilisation of the main drive transmission speeds which increase the total number of speeds achievable by the CFT alone; thus KERS efficiency is increased. The CFT may or may not be clutchable from the engine by engaging and disengaging a clutch located between the engine and main drive transmission (not shown). The CFT may or may not include a range extender; in this case, the CFT comprises three speeds and does not include a range extender. A range extender or second ratio set may optionally be may be included in series with the CFT in order to increase one or both of efficiency and operating ratio spread of the CFT. The main drive transmission output is coupled to the differential gear and final drive ratio.

Claims

1. A transmission for a vehicle mechanical kinetic energy recovery system (MKERS) comprising three ratio sets arranged in series, each ratio set comprising at least two selectable ratios connected in parallel with one another, wherein all ratios of one of the ratio sets are selectable by friction clutches.

2. A transmission according to claim 1 comprising an input that is caused to rotate at a speed proportional to the road-speed of the vehicle.

3. A transmission according to claim 2 in which the input is coupled to a final drive of the vehicle.

4. A transmission according to claim 3 which the input is coupled to a final drive of the vehicle by a drive-shaft.

5. A transmission according to any one of the preceding claims in which all of the selectable ratios of the transmission comprise friction clutches.

6. A transmission according to any one of the preceding claims wherein each clutch forms part of a clutch assembly and wherein at least two of the clutch assemblies are the same.

7. A transmission according to any one of the preceding claims in which each ratio set is offset laterally from the other ratio sets with respect to the longitudinal central axis of the vehicle.

8. A transmission according to any one of the preceding claims in which the rotational axes of all of the clutches are substantially parallel to one another.

9. A transmission according to claim 8 in which the rotational axes of all clutches are substantially parallel with a longitudinal central axis of the vehicle.

10. A transmission according to any one of the preceding claims in which a ratio spread of the transmission is 11 or greater.

11. A transmission according to any one of the preceding claims in which at least one of the clutches serves as a drive disconnect.

12. A transmission according to any one of the preceding claims wherein the plurality of clutches are arranged for operation in a slipping mode for the control and transmission of power to or from the flywheel, and further comprising means for supplying to the clutches a rate of oil flow that is a function of the magnitude of power transmitted to or from the flywheel.

13. A transmission according to any one of the preceding claims further comprising a controller that controls at least one of the clutches in a substantially continuously slipping mode throughout the duration of torque transfer through the transmission.

14. A transmission according to any one of the preceding claims further comprising a high speed flywheel.

15. A drivetrain for a vehicle comprising an engine, a variable speed main drive transmission, a final drive having an input coupled to an output of the variable speed transmission, a mechanical kinetic energy recovery system (MKERS) including a variable speed drive coupled between an input and a flywheel of the MKERS, the input to the MKERS being operatively coupled to the drivetrain such that it is caused to rotate at a speed proportional to the road-speed of the vehicle, wherein the MKERS comprises three ratio sets in series, each of the ratio sets comprising at least two clutches each with an associated ratio, each clutch and associated ratio connected in parallel with the other clutch and associated ratio of the same set, wherein the clutches of one of the ratio sets can operate in a slipping mode and in a non-driving (open) mode.

Intellectual Property Office

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Claims searched:	1-15	**Date of search:**	6 November 2015

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
A	-	GB 2476676 A (FLYBRID)
A	-	US 2014/0366682 A1 (MURATA)
A	-	US 4777837 A (LEHLE)
A	-	WO 98/40647 A1 (BOSCH)

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X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

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Worldwide search of patent documents classified in the following areas of the IPC

B60K; F16H

The following online and other databases have been used in the preparation of this search report

EPODOC, WPI, TXTA

International Classification:

Subclass	Subgroup	Valid From
B60K	0006/10	01/01/2006
B60K	0006/547	01/10/2007
F16H	0061/68	01/01/2006