

Title: Counteracting coupling assembly for force distribution in a rack and pinion system of a jackup vessel

5 FIELD

The invention relates to a rack and pinion system for jacking a hull of a jackup vessel with respect to one or more legs of the jackup vessel. The invention further relates to: a counteracting coupling assembly for distributing pinion rotational forces among pinion drive assemblies of a rack and pinion system; a jackup vessel provided with the rack and pinion system; a use of the rack and pinion system and/or of the counteracting coupling assembly; and methods.

BACKGROUND

15 A jackup vessel can be described as a self-elevating type of mobile offshore unit, that can be used to perform a range of offshore activities. Jackup vessels are equipped with extendable legs or jacks that can be lowered onto the seabed to provide a stable platform for the vessel. The term 'jacking' is commonly used to refer to the action of raising or lowering the hull of the vessel with respect to the legs, in particular to raise the hull above the sea surface.

Jackup vessels are versatile and highly manoeuvrable, making them a popular choice in the offshore industry for operations that require flexibility and adaptability, as they can be easily relocated to different locations. Jackup vessels are commonly used in offshore construction and maintenance activities such as drilling, exploration, installation of offshore wind turbines, oil and gas production, etc. Jackup vessels are also used for transport of heavy equipment, as a base for diving, as accommodation for personnel, etc.

30 Jackup vessels have been increasing in size and thus weight, demanding more and more of the jacking systems used. Upscaling of jacking

systems, especially rack and pinion systems, is typically difficult since the jacking system could become too large for the vessel. This could then lead to losing deck space and adding too much weight to the vessel. In the past, solutions have been found in increasing the number of drives of the jacking
5 system and/or in adjusting the way in which the jacking system is fixed to the vessel, e.g. using a so-called floating frame as alternative to direct mounting to the hull. An important requirement is to provide a continuous and robust jacking process.

When a vessel has been jacked, variable loads acting on the jackup
10 vessel tend to change the distribution of forces on the jacking system, in particular among pinions arranged at different levels. These variations in so-called holding torque on the different pinions may for example be due to lifting operations performed using a deck crane, but may also be due to wave and wind action.

15 Load distribution between the pinions during active jacking is typically balanced by the control system of the pinion drives when multiple pinion drives are coupled to the same rack. The control is typically such that each pinion has a similar load. The control of torque on the pinions can either be such that the motor is set to a constant torque, or such that the
20 motor is set to a constant speed needing a slip motor to equalize torque over the pinions. When the movement is stopped, the pinion drives are on a mechanical brake with the load distribution equalized over the pinions.

After the pinion drives have been put on their brake, any variation in load tends to result in differences in load between the pinions. The load
25 distribution between the pinions in these cases typically depends on the stiffnesses of the rack, the pinion drives, and related structures. An uneven distribution of the forces has several disadvantages, including uneven loading of the legs which causes uneven stresses in the legs. This in turn may result in structural damage, can affect the stability of the jackup vessel
30 causing it in extreme cases to tilt or lean to one side, and increasing wear

and tear on the pinion drives as some pinion drives may be subjected to more stress than others resulting in costly repairs and downtime. This can then result in reduced efficiency of the jackup vessel which can lead to slower operation and increased fuel consumption affecting the overall
5 performance of the vessel.

With jackup vessels getting larger, more is asked from the jacking system. When the jacking system is on brake and thus mechanically static, unevenness in load distribution over the different pinions will be larger than on smaller jackup vessels, needing quicker renewal of the pinions which will
10 carry the largest part of the load. The service life of heavily loaded pinions can in some cases be 30% less than that of other pinions. Also, the wearing due to slight movements between the different pinions and the rack and tearing due to loads working on the pinions is increased.

In the past, uneven load distributions have been addressed by
15 changing the way in which jacking systems were connected to the deck. A directly fixed jacking system will tend to distribute the loads in a so-called Christmas tree fashion over the different pinions, meaning that the lowest pinions will carry the largest loads and the upper pinions carry the smallest loads. By hanging the jacking system in an intermediate or 'floating' frame,
20 the load distribution tends to become distributed over the different pinions in a so-called banana fashion, meaning the upper and lower pinions will carry the largest loads and the middle pinion or pinions carry the smallest load. The trade-off is that a floating frame is larger in construction, asking more deck space and adding more weight. Also, the load distribution is then
25 still not fully evened out.

Meanwhile, systems have been developed that use a single motor for two or three pinions, mutually coupling these pinions either vertically or horizontally through gearing and thereby distributing the load over these pinions to some extent. Examples of such systems are disclosed in
30 FR2753466A1, US7581714B2 and US9702105B2. A disadvantage of such

systems is that the gearing generally needs to handle combined loads from the multiple pinions, in turn requiring relatively heavy and complex gearing. Moreover, it may be undesirable in some cases to use a single motor for multiple pinions, for example in view of controlling load distribution during jacking.

SUMMARY

An object of the invention is to improve static load distribution among pinion drive assemblies arranged at different levels, in particular so as to reduce or eliminate uneven static load distributions among the levels, e.g. during lifting operations and/or due to other time-variable loading conditions. An object is to enable such improvements without excessive increases in size or weight. An object is to enable such improvements in a relatively robust and easy to use manner.

To that end, an aspect of the invention provides a rack and pinion system for jacking a hull of a jackup vessel with respect to one or more legs of the jackup vessel. The rack and pinion system comprises: a rack arranged to be fixed to a leg of the jackup vessel; and at least two pinion drive assemblies arranged to be mounted to the hull at different respective pinion levels along the hull, each pinion drive assembly comprising at least one pinion rotatably drivable along the rack for jacking. The rack and pinion system further comprises at least one counteracting coupling assembly configured to selectively mutually couple or decouple pinion drive assemblies of the at least two pinion drive assemblies such that respective pinion rotational forces of the pinion drive assemblies, when mutually coupled, counteract each other via the at least one counteracting coupling assembly.

When the rack and pinion system is not actively used for jacking, pinion rotational forces tend to occur at the pinions of the pinion drive assemblies mainly due to loading of the hull as well as due to the weight of

the hull itself. Traditionally, such rotational forces are then prevented from causing rotational motion of the pinion using respective brakes of the pinion drive assemblies. Although generally effective to prevent pinion motion, such brakes are typically unable to influence how loading forces are distributed among respective pinions of different pinion drive assemblies. The present invention is based on the insight that a counteracting coupling assembly as described can be provided to cause such force distribution among different levels of pinion drive assemblies to become more even compared to a traditional multilevel rack and pinion system of a jackup vessel. The counteracting coupling assembly may be provided e.g. in addition to the respective brakes, but could even allow some or all of those brakes to be omitted. When pinion drive assemblies are coupled by the counteracting coupling assembly, any such brake is preferably disengaged to allow effective force balancing among the pinion drive assemblies.

When the counteracting coupling assembly mutually decouples the respective pinion drive assemblies, i.e. when the respective pinion rotational forces are not caused to counteract each other, the rack and pinion system can be used for active jacking essentially in the same manner as a traditional rack and pinion jacking system. This typically involves respective motors of the pinion drive assemblies being controlled to cause the respective pinions to rotate so as to move along the rack. A controller controlling the motors may promote force distribution among the pinion drive assemblies during the jacking.

When active jacking is not performed, i.e. in a generally static situation during so-called 'holding', the counteracting coupling assembly may couple the respective pinion drive assemblies as described, causing the respective pinion rotational forces, also known as 'holding torques', to counteract each other. Advantageously, this counteraction of the rotational forces will tend to result in an even, or at least more even, distribution of those forces among the respective pinions. Without wishing to be bound by

theory, it is believed that this advantageous effect can be understood based on Newton's third law of motion. Meanwhile, the same counteraction of forces may advantageously prevent the pinions from rotating, thereby obviating the need to apply separate brakes. As indicated above, any such
5 brakes are in fact preferably disengaged to allow the desired force balancing.

Thanks to the more even force distribution, wear of the pinions will generally be reduced, in particular for pinions that would traditionally be prone to high loads and/or to large variations in loading. In turn, the
10 reduced wear may lead to increased pinion lifetime and reduced maintenance, yielding improved overall performance of the jackup vessel.

The counteracting coupling assembly can be realized in a relatively simple and robust manner in various ways, as explained elsewhere herein.

The at least two pinion drive assemblies may each comprise a
15 motor and a transmission between the motor and the at least one pinion, the transmission being configured to convert a high-speed low-torque input from the motor to a low-speed high-torque output to the at least one pinion. Preferably, the at least one counteracting coupling assembly is then configured to engage with the pinion drive assemblies at parts of the
20 respective transmissions that have high speed and low torque compared to the respective pinion, for example parts having a speed and torque corresponding to the respective motor, such as motor shafts of the motor. In other words, the at least one counteracting coupling assembly is preferably configured to engage with the pinion drive assemblies at same sides of the
25 transmission as the respective motors, or at least closer to the motor side than to the pinion side of the transmission.

In this way, advantageously, the relatively high holding torques at the pinions can be balanced using a relatively low torque coupling at the counteracting coupling assembly. Thereby, the counteracting coupling
30 assembly can be made relatively small and light weight. Meanwhile, the

transmissions can be utilized not only during jacking but also during holding, thus serving a double function. A transmission ratio of the transmission may be at least 1:1000, at least 1:2000, or at least 1:5000, for example about 1:7000 or about 1:8000. Thereby, depending on where with
5 respect to the transmission the counteracting coupling assembly is coupled, a torque on the counteracting coupling assembly may be reduced compared to the holding torque at the pinions themselves by the same or a similar ratio.

The pinion drive assemblies to be coupled may have a common
10 rotational driving direction for jacking the hull with respect to the leg. Preferably, the at least one counteracting coupling assembly then comprises a respective inversion mechanism configured to allow the respective pinion rotational forces of said pinion drive assemblies to counteract each other when coupled by the at least one counteracting coupling assembly.

15 Such an inversion mechanism can advantageously facilitate the described counteraction, in particular without affecting the common rotational driving direction itself. The inversion mechanism can be realized in various ways, as will be explained further herein.

Optionally, the inversion mechanism comprises a set of angled
20 gearboxes, e.g. right-angled gearboxes.

A gearbox is considered an angled gearbox when its output rotational axis is at an angle to its input rotational axis, the angle being different from 180 degrees and different from 360 degrees. The angle may for example be a right angle, so that the angled gearbox is a so-called right-
25 angled gearbox. It is preferred that the set of angled gearboxes is a set of such right-angled gearboxes, although non-right angles are possible as well. A gear ratio of the angled gearboxes is preferably about 1:1, but may be alternatively be somewhat different, e.g. 1:2 or 2:1. Excessive gear ratios for the angled gearboxes are in most cases not preferred, in particular since a
30 desired transmission ratio with respect to the pinions may already be

available from the transmissions of the pinion drives themselves, as explained above. Nevertheless, a non-unitary gear ratio may be applied in the angled gearboxes to reduce torque, e.g. to enable weight and/or size reduction for a shaft of the counteracting coupling assembly, in particular a
5 shaft via which the angled gearboxes can be mutually coupled, as explained further elsewhere herein.

The angled gearboxes can advantageously enable the respective pinion drive assemblies to be mutually coupled across their different levels, in particular along an axis that spans the different levels. Meanwhile, the
10 arrangements and designs of the angled gearboxes can be chosen such that relative rotational directions at the inputs and outputs of the angled gearboxes result in an inversion, so that the angled gearboxes may form at least part of the inversion mechanism, in particular when the angled gearboxes are mutually coupled.

15 Optionally, the angled gearboxes are coupled to respective ones of the pinion drive assemblies, wherein the at least one counteracting coupling assembly is configured to selectively mutually couple or decouple the angled gearboxes.

Thus, the selective coupling or decoupling of the pinion drive
20 assemblies may be realized by selective coupling or decoupling of the angled gearboxes. Advantageously, a switchable coupling mechanism such as a clutch may thus be arranged between the pinion drive assemblies, where sufficient space may be available without necessarily requiring modifications in the pinion drive assemblies themselves.

25 Optionally, the at least one counteracting coupling assembly comprises a clutch configured to mutually couple the pinion drive assemblies when engaged and to mutually decouple the pinion drive assemblies when disengaged.

Such a clutch can provide an effective and robust means to provide the selective coupling or decoupling of the pinion drive assemblies, for example between the optional angled gearboxes.

Optionally, the at least one counteracting coupling assembly
5 comprises a shaft or shaft assembly, preferably comprising a cardan shaft, extending between the pinion drive assemblies to be coupled, in particular at an angle to rotational axes of the pinions.

Thereby, the pinion drive assemblies can advantageously be coupled across their different levels, in particular in combination with
10 angled gearboxes as described, which may then be couplable via the shaft. A cardan shaft is preferred in order to resolve possible small misalignments, and moreover to enable the shaft assembly to go around any structures arranged between the pinion drive assemblies to be coupled, e.g. extending along a zigzagging or meandering path. Preferably, the shaft or shaft
15 assembly extends transverse to the typically horizontal rotational axes of the pinions, e.g. extending mainly vertically.

As a possible alternative or addition to a mechanical coupling such as using the angled gearboxes, clutch and/or shaft, a counteracting coupling assembly may be configured to provide a hydraulic coupling between the
20 pinion drive assemblies. Hydraulic pressures from the different pinion drive assemblies, corresponding to the respective pinion rotational forces, may then be caused to selectively counteract or not counteract each other, e.g. using one or more valves. Nevertheless, a non-hydraulic mechanical coupling is preferred, in particular to promote robustness of the coupling
25 under typically challenging operating conditions at sea.

Optionally, each counteracting coupling assembly of the at least one counteracting coupling assembly is configured to selectively mutually couple or decouple two and only two of the pinion drive assemblies, in particular so that each pinion drive assembly is couplable to only one other
30 pinion drive assembly by the at least one counteracting coupling assembly.

In this way, a more even distribution of holding torques can be realized in a relatively simple yet precise manner, in particular among one or more pairs of pinion drive assemblies that might typically have different holding torques. Nevertheless, it shall be appreciated that a counteracting
5 coupling assembly may be configured to selectively mutually couple or decouple more than two pinion drive assemblies. For example, one pinion drive assembly associated with a higher torque may be coupled with two pinion drive assemblies associated with a lower torque, in particular if the lower-torque assemblies are relatively close to each other compared to each
10 of their distances to the higher-torque assembly, or if the higher-torque assembly is in between the lower-torque assemblies. To promote a relatively even load balancing, a gear ratio of the preferred angled gearboxes may then be adjusted depending on the specifics of the arrangement.

Optionally, a counteracting coupling assembly of the at least one
15 counteracting coupling assembly is configured to selectively mutually couple or decouple pinion drive assemblies that are not mutually adjacent, in particular bridging one or more intermediate pinion drive assemblies arranged between pinion drive assemblies to be mutually coupled by the counteracting coupling assembly.

20 In this way, advantageously, pinion drive assemblies can be matched into suitable pairs to promote a relatively even force distribution among the pinion drive assemblies. In this respect, it is noted that holding torques of decoupled pinion drive assemblies may be more different as the respective pinions are further apart along part or all of the rack, e.g. leading
25 to the typical Christmas tree type or banana type force distribution as referred to in the background section. In view thereof, it is preferred that the counteracting coupling assemblies are not limited to coupling adjacent pinion drive assemblies only, so that, for the selective coupling and force balancing, pinion drive assemblies can be matched into suitable pairs. For
30 example, a pinion drive assembly normally having a high holding torque

may be matched with a pinion drive assembly normally having a correspondingly low holding torque, and so on for most or all pinion drive assemblies, resulting in a relatively even overall force distribution, i.e. with most or all remaining torque differences between pinions being close to zero.

5 Optionally, the number of pinion drive assemblies of the at least two pinion drive assemblies is at least four, wherein the number of counteracting coupling assemblies of the at least one counteracting coupling assembly is at least two.

 In this way, a relatively powerful rack and pinion system can be
10 provided in which holding forces can be distributed through multiple couplable sets of pinion drive assemblies.

 The at least four pinion drive assemblies may comprise a first, a second, a third and a fourth pinion drive assembly, arranged to be mounted at corresponding subsequent first, second, third and fourth pinion levels,
15 respectively. Optionally, the counteracting coupling assemblies then comprise a counteracting coupling assembly configured to selectively mutually couple or decouple the first and the third pinion drive assembly, and/or a counteracting coupling assembly configured to selectively mutually couple or decouple the second and the fourth pinion drive assembly.

20 In this way, pinion drive assemblies can be selectively mutually coupled in an interweaving or interlacing fashion, allowing counteraction of pinion rotational forces among pinion drive assemblies arranged directly above and below an intermediate pinion drive assembly. Such an arrangement may yield more effective load balancing than when only
25 mutually adjacent pinion drive assemblies are mutually coupled. Meanwhile, the distances between coupled pinion drive assemblies and thus the corresponding sizes of the coupling assemblies can still be relatively small.

 The number of pinion drive assemblies of the at least four pinion
30 drive assemblies may be n , wherein the n pinion drive assemblies comprise

a first, a second, an $n-1^{\text{th}}$ and an n^{th} pinion drive assembly, arranged to be mounted at corresponding first, second, $n-1^{\text{th}}$ and n^{th} pinion levels, respectively. Optionally, the counteracting coupling assemblies then comprise a counteracting coupling assembly configured to selectively
5 mutually couple or decouple the first and the n^{th} pinion drive assembly and/or a counteracting coupling assembly configured to selectively mutually couple or decouple the second and the $n-1^{\text{th}}$ pinion drive assembly.

In this way, pinion drive assemblies from a set arranged along the rack can be mutually coupled in pairs that are matched according to their
10 position within the set being correspondingly central or decentral in the set. Advantageously, a traditional Christmas tree or banana type load distribution can thereby be substantially evened out when the pinion drive assemblies are coupled.

A further aspect provides a counteracting coupling assembly for
15 distributing pinion rotational forces among pinion drive assemblies of a rack and pinion system, in particular as described herein, configured to selectively mutually couple or decouple pinion drive assemblies of a rack and pinion system for jacking a hull of a jackup vessel with respect to a leg of the jackup vessel, such that respective pinion rotational forces of the
20 pinion drive assemblies, when mutually coupled, counteract each other via the at least one counteracting coupling assembly.

Such a counteracting coupling assembly can advantageously provide above described advantages, for example when retrofitted to a rack and pinion system of a jackup vessel.

25 It shall be appreciated that optional features described above in relation to the rack and pinion system may be correspondingly applied to the counteracting coupling assembly.

The coupling assembly may thus comprise: a set of angled gearboxes to be coupled to respective pinion drive assemblies, so as to form
30 part of an inversion mechanism configured to allow the respective pinion

rotational forces of said pinion drive assemblies to counteract each other when the angled gearboxes are mutually coupled; and a clutch for mutually coupling the angled gearboxes when the clutch is engaged, such that, in use, the respective pinion rotational forces counteract each other via the at least
5 one counteracting coupling assembly, wherein the angled gearboxes are mutually decoupled when the clutch is disengaged, such that the respective pinion drive assemblies can be driven for jacking.

A further aspect provides a jackup vessel provided with one or more rack and pinion systems as described herein, for jacking a hull of the
10 jackup vessel with respect to one or more legs of the jackup vessel, wherein the respective one or more racks are fixed to respective one or more legs of the jackup vessel, wherein the respective pinion drive assemblies are mounted to the hull.

Such a jackup vessel can provide above described advantages.

15 A further aspect provides a use of a rack and pinion system as described herein and/or a counteracting coupling assembly as described herein for distributing pinion rotational forces among pinion drive assemblies at different levels along a hull of a jackup vessel supported on legs of the vessel, in particular under dynamic loading of the hull such as
20 during lifting operations.

Such a use can provide above described advantages.

A further aspect provides a method of distributing pinion rotational forces among pinion drive assemblies at different levels along a hull of a jackup vessel supported on legs of the vessel, in particular under dynamic
25 loading of the hull such as during lifting operations, the method comprising causing the pinion drive assemblies to be releasably mutually coupled such that respective pinion rotational forces of the mutually coupled pinion drive assemblies counteract each other.

Such a method can provide advantages corresponding to those described above for the rack and pinion system, the counteracting coupling assembly and/or the vessel.

A further aspect provides a method of retrofitting at least one
5 counteracting coupling assembly to one or more rack and pinion systems of a jackup vessel. The method of retrofitting comprises providing a rack and pinion system for jacking a hull of a jackup vessel with respect to a leg of the jackup vessel, comprising: a rack fixed to a leg of the jackup vessel; and at least two pinion drive assemblies mounted to the hull at different respective
10 pinion levels along the hull, each pinion drive assembly comprising at least one pinion rotatably drivable along the rack for jacking the hull with respect to the leg. The method of retrofitting further comprises: providing at least one counteracting coupling assembly, in particular as described herein, for selectively mutually coupling or decoupling pinion drive assemblies of the at
15 least two pinion drive assemblies; and mounting the at least one counteracting coupling assembly to pinion drive assemblies of the at least two pinion drive assemblies such that respective pinion rotational forces of the pinion drive assemblies, when mutually coupled, counteract each other via the at least one counteracting coupling assembly.

20 Such a method can provide advantages corresponding to those described above, in particular without requiring e.g. partial or full replacement of an existing rack and pinion system of a jackup vessel.

Although for purposes of clarity and a concise description features may be described herein as relating to one or some of the described aspects,
25 it shall be appreciated that such features may correspondingly be applied in other aspects, in particular where the aspects are interrelated. Thus, for example, features described in relation to a system or assembly may be correspondingly applied in a method, and vice versa.

30 DETAILED DESCRIPTION

In the following, the invention will be explained further using examples of embodiments and drawings. The drawings are schematic and merely show examples. In the drawings, corresponding elements have been provided with corresponding reference signs. In the drawings:

5 Fig. 1 shows a side view of a jackup vessel;

 Figs. 2A and 2B each show a theoretical diagram of a rack and pinion system with a counteracting coupling assembly in side view, wherein in Fig. 2A the pinions are in an unloaded or jacking condition with respect to the rack, and wherein in Fig. 2B the pinions are in a loaded or holding
10 condition with respect to the rack;

 Fig. 3 shows a front view of pinion drive assemblies with a counteracting coupling assembly;

 Figs. 4A to 4D each show a diagram of a rack and pinion system according to different respective variants of arrangements of pinion drive
15 assemblies and one or more counteracting coupling assemblies;

 Fig. 5 shows a front view of pinion drive assemblies with a counteracting coupling assembly;

 Fig. 6 shows a side view of a set of two counteracting coupling assemblies, corresponding to an arrangement shown in Fig. 4C; and

20 Fig. 7 shows a diagram of a rack and pinion system according to a further possible variant.

 The figures show various views of examples of a rack and pinion system 1 for jacking a hull 2 of a jackup vessel 3 with respect to one or more legs 4 of the jackup vessel 3. The system 1 comprises: a rack 5 arranged to
25 be fixed to a leg 4 of the jackup vessel; and at least two pinion drive assemblies 6 arranged to be mounted to the hull 2 at different respective pinion levels along the hull 2, each pinion drive assembly 6 comprising at least one pinion 7 rotatably drivable along the rack 5 for jacking.

 The system 1 further comprises at least one counteracting coupling
30 assembly 8 configured to selectively mutually couple or decouple pinion

drive assemblies 6 of the at least two pinion drive assemblies 6 such that respective pinion rotational forces of the pinion drive assemblies 6, when mutually coupled, counteract each other via the at least one counteracting coupling assembly 8.

5 The figures also show various views of examples of a counteracting coupling assembly 8 for distributing pinion rotational forces among pinion drive assemblies 6 of a rack and pinion system 1. The counteracting coupling assembly 8 is configured to selectively mutually couple or decouple pinion drive assemblies 6 of a rack and pinion system 1 for jacking a hull 2
10 of a jackup vessel 3 with respect to a leg 4 of the jackup vessel 3, such that respective pinion rotational forces of the pinion drive assemblies 6, when mutually coupled, counteract each other via the at least one counteracting coupling assembly 8.

One or more such counteracting coupling assemblies 8 may be
15 retrofitted to one or more rack and pinion systems 1 of a jackup vessel 3. The method of retrofitting comprises providing a rack and pinion system 1 for jacking a hull 2 of a jackup vessel 3 with respect to a leg 4 of the jackup vessel 3, the rack and pinion system 1 comprising: a rack 5 fixed to a leg 4 of the jackup vessel; and at least two pinion drive assemblies 6 mounted to the
20 hull 2 at different respective pinion levels along the hull 2, each pinion drive assembly 6 comprising at least one pinion 7 rotatably drivable along the rack 5 for jacking the hull 2 with respect to the leg 4. The method of retrofitting further comprises: providing at least one counteracting coupling assembly 8 for selectively mutually coupling or decoupling pinion drive
25 assemblies 6 of the at least two pinion drive assemblies 6; and mounting the at least one counteracting coupling assembly 8 to pinion drive assemblies 6 of the at least two pinion drive assemblies 6 such that respective pinion rotational forces of the pinion drive assemblies 6, when mutually coupled, counteract each other via the at least one counteracting coupling assembly
30 8.

Fig. 1 shows a jackup vessel 3 provided with one or more rack and pinion systems 1, for jacking a hull 2 of the jackup vessel 3 with respect to one or more legs 4 of the jackup vessel 3, wherein the respective one or more racks 5 are fixed to respective one or more legs 4 of the jackup vessel 3,
5 wherein the respective pinion drive assemblies 6 are mounted to the hull 2.

The rack and pinion system 1 and/or the counteracting coupling assembly 8 may thus be used for distributing pinion rotational forces among pinion drive assemblies 6 at different levels along a hull 2 of a jackup vessel 3 supported on legs 4 of the vessel 3, in particular under dynamic loading of
10 the hull 2 such as during lifting operations.

The figures also illustrate a method of distributing pinion rotational forces among pinion drive assemblies 6 at different levels along a hull 2 of a jackup vessel 3 supported on legs 4 of the vessel 3, in particular under dynamic loading of the hull 2 such as during lifting operations, the
15 method comprising causing the pinion drive assemblies 6 to be releasably mutually coupled such that respective pinion rotational forces of the mutually coupled pinion drive assemblies 6 counteract each other.

With particular reference to Fig. 3, the at least two pinion drive assemblies 6 may each comprise a motor 9 and a transmission 10 between
20 the motor 9 and the at least one pinion 7, the transmission 10 being configured to convert a high-speed low-torque input from the motor 9 to a low-speed high-torque output to the at least one pinion 7, wherein the at least one counteracting coupling assembly 8 is configured to engage with the pinion drive assemblies 6 at parts of the respective transmissions 10 that
25 have high speed and low torque compared to the respective pinion 7, for example parts having a speed and torque corresponding to the respective motor 9, such as motor shafts 11 of the motor 9.

The transmission 10 may for example comprise a planetary gearbox 10a and a drop gearbox 10b. The pinion drive assembly 6 may
30 further comprise a brake 16, for example an electromagnetic brake.

The angled gearboxes 13 described elsewhere herein may thus be coupled to the motor shafts 11, for example between the motors 9 and optional brakes 16, as shown in Fig. 3, or alternatively between the motors 9 and the transmissions 10. Although less preferred, the angled gearboxes
5 could also be arranged between different parts 10a, 10b of the transmissions 10.

With reference to the diagrams of Figs. 2A and 2B, the pinion drive assemblies 6 to be coupled may have a common rotational driving direction D for jacking the hull 2 with respect to the leg 4, wherein the at least one
10 counteracting coupling assembly 8 comprises a respective inversion mechanism 12 configured to allow the respective pinion rotational forces of said pinion drive assemblies 6 to counteract each other when coupled by the at least one counteracting coupling assembly 8.

Returning to Fig. 3, the inversion mechanism 12 may comprise a
15 set of angled gearboxes 13.

The angled gearboxes 13 may be coupled to respective ones of the pinion drive assemblies 6, wherein the at least one counteracting coupling assembly 7 is configured to selectively mutually couple or decouple the angled gearboxes 13.

20 The at least one counteracting coupling assembly 8 may comprise a clutch 14 configured to mutually couple the pinion drive assemblies 6 when engaged and to mutually decouple the pinion drive assemblies 6 when disengaged. The clutch 14 may be a spring loaded electromagnetic clutch.

The at least one counteracting coupling assembly 8 may comprise a
25 shaft or shaft assembly 15 extending between the pinion drive assemblies 6 to be coupled, in particular at an angle to rotational axes R of the pinions.

With reference to Figs. 5 and 6, the shaft assembly 15 may comprise a cardan shaft 23.

Thus, the counteracting coupling assembly 8 may comprise: a set of
30 angled gearboxes 13 to be coupled to respective pinion drive assemblies 6, so

as to form part of an inversion mechanism 12 configured to allow the respective pinion rotational forces of said pinion drive assemblies 6 to counteract each other when the angled gearboxes 13 are mutually coupled; and a clutch 14 for mutually coupling the angled gearboxes when the clutch
5 14 is engaged, such that, in use, the respective pinion rotational forces counteract each other via the at least one counteracting coupling assembly 8, wherein the angled gearboxes 13 are mutually decoupled when the clutch 14 is disengaged, such that the respective pinion drive assemblies 6 can be driven for jacking.

10 To facilitate automated control of the counteracting coupling assembly 8 and/or the pinion drive assembly 6 and/or the rack and pinion system 1, one or more of the angled gearboxes 13 may be provided with an encoder 21, e.g. as shown in Figs. 5 and 6.

In the shown examples, each counteracting coupling assembly 8 of
15 the at least one counteracting coupling assembly 8 is configured to selectively mutually couple or decouple two and only two of the pinion drive assemblies 6, so that each pinion drive assembly 6 is couplable to only one other pinion drive assembly 6 by the at least one counteracting coupling assembly 8.

20 With reference to Figs. 4B, 4C and 4D, a counteracting coupling assembly 8 of the at least one counteracting coupling assembly 8 may be configured to selectively mutually couple or decouple pinion drive assemblies 6 that are not mutually adjacent, in particular bridging one or more intermediate pinion drive assemblies 6 arranged between pinion drive
25 assemblies 6 to be mutually coupled by the counteracting coupling assembly 8.

With reference to Figs. 4C and 4D, the number of pinion drive assemblies 6 of the at least two pinion drive assemblies 6 may be at least four, wherein the number of counteracting coupling assemblies 7 of the at
30 least one counteracting coupling assembly 8 is at least two.

With reference to Fig. 4C, the at least four pinion drive assemblies 6 may comprise a first, a second, a third and a fourth pinion drive assembly 6, arranged to be mounted at corresponding subsequent first, second, third and fourth pinion levels, respectively. The counteracting coupling assemblies 8 may then comprise a counteracting coupling assembly 8 configured to selectively mutually couple or decouple the first and the third pinion drive assembly 6, and/or a counteracting coupling assembly 8 configured to selectively mutually couple or decouple the second and the fourth pinion drive assembly 6.

With reference to Fig. 4D, the number of pinion drive assemblies 6 of the at least four pinion drive assemblies 6 may be n , wherein the n pinion drive assemblies 6 comprise a first, a second, an $n-1^{\text{th}}$ and an n^{th} pinion drive assembly 6, arranged to be mounted at corresponding first, second, $n-1^{\text{th}}$ and n^{th} pinion levels, respectively. The counteracting coupling assemblies 8 may then comprise a counteracting coupling assembly 8 configured to selectively mutually couple or decouple the first and the n^{th} pinion drive assembly 6 and/or a counteracting coupling assembly configured to selectively mutually couple or decouple the second and the $n-1^{\text{th}}$ pinion drive assembly 6.

With reference to Fig. 4B, for any pinion drive assembly 6 not associated with a counteracting coupling assembly 8, see e.g. the middle pinion drive assembly 6 in Fig. 4B, a conventional brake 16 is preferably engaged while other pinion drive assemblies 6 are mutually coupled by a counteracting coupling assembly 8.

Fig. 7 shows an example of a possible further elaboration, wherein a mutual coupling 24 of counteracting coupling assemblies 8 is provided. In this way, for example, counteracting couplings among pairs of pinion drive assemblies 6 using respective counteracting coupling assemblies 8 can be complemented by a mutual coupling of those counteracting coupling assemblies 8, enabling still further advantageous load distribution.

Advantageously, pinion loads can thus be distributed relatively evenly among relatively large numbers of pinion levels. With reference to Figs. 4C and 4D, it shall be appreciated that such a mutual coupling of counteracting coupling assemblies 8 may correspondingly be applied in the arrangements shown there, by mutually coupling the multiple counteracting coupling assemblies 8 shown there. By thus coupling pinion drive assemblies first in pairs and subsequently among those pairs, and particularly well balanced system can be realized. It shall be appreciated that this multi-staged elaboration of the general counteracting coupling principle can in principle be carried out with as many stages of couplings as may be needed or desired in view of the number of pinion levels in the system. For example, in case of eight pinion levels, the arrangement of Fig. 7 may be provided twice, wherein the then two mutual couplings 24 may in turn be mutually coupled, resulting in a three-stage counteracting coupling arrangement in which loads from each pinion level of eight pinion levels can be directly or indirectly distributed to each other pinion level. Nevertheless, it shall be appreciated that this merely represents an optional elaboration, and that more generally such a high degree of load distribution is not essential.

Although the invention has been explained herein using examples of embodiments and drawings, these do not limit the scope of the invention as defined by the claims. Within said scope, many variations, combinations and extensions are possible, as will be appreciated by the skilled person having the benefit of the present disclosure. For example, although shown examples include up to four levels or layers of pinion drive assemblies, a rack and pinion system may include more than four such levels, for example up to eight levels or more. Also, while the shown examples include a single pinion per pinion drive assembly, a pinion drive assembly may include multiple pinions, e.g. drivable by a same motor. All such variants are considered included within the scope of the invention as defined by the claims.

LIST OF REFERENCE SIGNS

	1.	Rack and pinion system
	2.	Hull
	3.	Jackup vessel
5	4.	Leg
	5.	Rack
	6.	Pinion drive assembly
	7.	Pinion
	8.	Counteracting coupling assembly
10	9.	Motor
	10.	Transmission
	10a.	Planetary gearbox
	10b.	Drop gearbox
	11.	Motor shaft
15	12.	Inversion mechanism
	13.	Angled gearbox
	14.	Clutch
	15.	Shaft or shaft assembly
	16.	Brake
20	17.	Crane
	18.	Crane load
	19.	Sea
	20.	Sea floor
	21.	Encoder
25	22.	Shaft housing
	23.	Cardan shaft
	24.	Mutual coupling of counteracting coupling assemblies
	D.	Rotational driving direction of pinion
	L.	Load
30	R.	Rotational axis of pinion

Claims

1. Rack and pinion system for jacking a hull of a jackup vessel with respect to one or more legs of the jackup vessel, comprising:
 - a rack arranged to be fixed to a leg of the jackup vessel; and
 - at least two pinion drive assemblies arranged to be mounted to
- 5 the hull at different respective pinion levels along the hull, each pinion drive assembly comprising at least one pinion rotatably drivable along the rack for jacking; and
 - at least one counteracting coupling assembly configured to
- 10 selectively mutually couple or decouple pinion drive assemblies of the at least two pinion drive assemblies such that respective pinion rotational forces of the pinion drive assemblies, when mutually coupled, counteract each other via the at least one counteracting coupling assembly.
2. Rack and pinion system according to claim 1, wherein the at least
- 15 two pinion drive assemblies each comprise a motor and a transmission between the motor and the at least one pinion, the transmission being configured to convert a high-speed low-torque input from the motor to a low-speed high-torque output to the at least one pinion, wherein the at least one counteracting coupling assembly is configured to engage with the pinion
- 20 drive assemblies at parts of the respective transmissions that have high speed and low torque compared to the respective pinion, for example parts having a speed and torque corresponding to the respective motor, such as motor shafts of the motor.
- 25 3. Rack and pinion system according to claim 1 or 2, wherein the pinion drive assemblies to be coupled have a common rotational driving direction for jacking the hull with respect to the leg, wherein the at least one

counteracting coupling assembly comprises a respective inversion mechanism configured to allow the respective pinion rotational forces of said pinion drive assemblies to counteract each other when coupled by the at least one counteracting coupling assembly.

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4. Rack and pinion system according to any of the preceding claims, wherein the inversion mechanism comprises a set of angled gearboxes.

5. Rack and pinion system according to claim 4, wherein the angled
10 gearboxes are coupled to respective ones of the pinion drive assemblies, wherein the at least one counteracting coupling assembly is configured to selectively mutually couple or decouple the angled gearboxes.

6. Rack and pinion system according to any of the preceding claims,
15 wherein the at least one counteracting coupling assembly comprises a clutch configured to mutually couple the pinion drive assemblies when engaged and to mutually decouple the pinion drive assemblies when disengaged.

7. Rack and pinion system according to any of the preceding claims,
20 wherein the at least one counteracting coupling assembly comprises a shaft or shaft assembly, preferably comprising a cardan shaft, extending between the pinion drive assemblies to be coupled, in particular at an angle to rotational axes of the pinions.

25 8. Rack and pinion system according to any of the preceding claims, wherein each counteracting coupling assembly of the at least one counteracting coupling assembly is configured to selectively mutually couple or decouple two and only two of the pinion drive assemblies, so that each pinion drive assembly is couplable to only one other pinion drive assembly
30 by the at least one counteracting coupling assembly.

9. Rack and pinion system according to any of the preceding claims, wherein a counteracting coupling assembly of the at least one counteracting coupling assembly is configured to selectively mutually couple or decouple pinion drive assemblies that are not mutually adjacent, in particular
- 5 bridging one or more intermediate pinion drive assemblies arranged between pinion drive assemblies to be mutually coupled by the counteracting coupling assembly.
10. Rack and pinion system according to any of the preceding claims, wherein the number of pinion drive assemblies of the at least two pinion drive assemblies is at least four, wherein the number of counteracting coupling assemblies of the at least one counteracting coupling assembly is at least two.
- 15 11. Rack and pinion system according to claim 10, wherein the at least four pinion drive assemblies comprise a first, a second, a third and a fourth pinion drive assembly, arranged to be mounted at corresponding subsequent first, second, third and fourth pinion levels, respectively, wherein the counteracting coupling assemblies comprise a
- 20 counteracting coupling assembly configured to selectively mutually couple or decouple the first and the third pinion drive assembly, and/or a counteracting coupling assembly configured to selectively mutually couple or decouple the second and the fourth pinion drive assembly.
- 25 12. Rack and pinion system according to claim 10, wherein the number of pinion drive assemblies of the at least four pinion drive assemblies is n , wherein the n pinion drive assemblies comprise a first, a second, an $n-1^{\text{th}}$ and an n^{th} pinion drive assembly, arranged to be mounted at corresponding first, second, $n-1^{\text{th}}$ and n^{th} pinion levels, respectively,

wherein the counteracting coupling assemblies comprise a counteracting coupling assembly configured to selectively mutually couple or decouple the first and the n^{th} pinion drive assembly and/or a counteracting coupling assembly configured to selectively mutually couple
5 or decouple the second and the $n-1^{\text{th}}$ pinion drive assembly.

13. Counteracting coupling assembly for distributing pinion rotational forces among pinion drive assemblies of a rack and pinion system, in particular according to any of the preceding claims, configured to
10 selectively mutually couple or decouple pinion drive assemblies of a rack and pinion system for jacking a hull of a jackup vessel with respect to a leg of the jackup vessel, such that respective pinion rotational forces of the pinion drive assemblies, when mutually coupled, counteract each other via the at least one counteracting coupling assembly.

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14. Counteracting coupling assembly according to claim 13, comprising:

- a set of angled gearboxes to be coupled to respective pinion drive assemblies, so as to form part of an inversion mechanism configured to allow
20 the respective pinion rotational forces of said pinion drive assemblies to counteract each other when the angled gearboxes are mutually coupled; and
- a clutch for mutually coupling the angled gearboxes when the clutch is engaged, such that, in use, the respective pinion rotational forces counteract each other via the at least one counteracting coupling assembly,
25 wherein the angled gearboxes are mutually decoupled when the clutch is disengaged, such that the respective pinion drive assemblies can be driven for jacking.

15. Jackup vessel provided with one or more rack and pinion systems
30 according to any of claims 1 – 12, for jacking a hull of the jackup vessel with

respect to one or more legs of the jackup vessel, wherein the respective one or more racks are fixed to respective one or more legs of the jackup vessel, wherein the respective pinion drive assemblies are mounted to the hull.

5 16. Use of a rack and pinion system according to any of claims 1 – 12 and/or a counteracting coupling assembly according to claim 13 or 14 for distributing pinion rotational forces among pinion drive assemblies at different levels along a hull of a jackup vessel supported on legs of the vessel, in particular under dynamic loading of the hull such as during lifting
10 operations.

17. Method of distributing pinion rotational forces among pinion drive assemblies at different levels along a hull of a jackup vessel supported on legs of the vessel, in particular under dynamic loading of the hull such as
15 during lifting operations, the method comprising causing the pinion drive assemblies to be releasably mutually coupled such that respective pinion rotational forces of the mutually coupled pinion drive assemblies counteract each other.

20 18. Method of retrofitting at least one counteracting coupling assembly to one or more rack and pinion systems of a jackup vessel, comprising:

- providing a rack and pinion system for jacking a hull of a jackup vessel with respect to a leg of the jackup vessel, comprising: a rack fixed to a
25 leg of the jackup vessel; and at least two pinion drive assemblies mounted to the hull at different respective pinion levels along the hull, each pinion drive assembly comprising at least one pinion rotatably drivable along the rack for jacking the hull with respect to the leg;
- providing at least one counteracting coupling assembly, in
30 particular according to claim 13 or 14, for selectively mutually coupling or

- decoupling pinion drive assemblies of the at least two pinion drive assemblies; and
- mounting the at least one counteracting coupling assembly to pinion drive assemblies of the at least two pinion drive assemblies such that
- 5 respective pinion rotational forces of the pinion drive assemblies, when mutually coupled, counteract each other via the at least one counteracting coupling assembly.