



AN APPARATUS FOR DETECTING MOTION IRREGULARITIES FOR RACK AND PINION SYSTEM

BACKGROUND OF THE INVENTION

This invention relates to an offshore industry and, more particularly, to an apparatus for use with rack and pinion systems of jack-up rigs.

Oil and gas exploration industry has used jack-up rigs for decades now. This type of structure provides for an elevated platform supported by a plurality of legs that move within wells formed in the platform. During transport to the exploration or production site, the legs are elevated above the platform. Once the platform is delivered to the operational site, it is elevated above anticipated wave action, while the legs move downwardly for positioning on the ocean floor.

Conventional jacking systems utilize racks and pinions for moving the legs; usually there are nine jacking assemblies, three assemblies for legs that have three leg chords. Each jacking assembly unit has four to six pinions, which are housed in a jack frame and supported on bearings. Each pinion is independently driven by an electric motor via gear trains.

When the jacking system encounters an obstruction, the jacking system becomes jammed. The same condition may result from a failed brake while the power continues to be supplied to the drive system. Conventional systems with electric motors are equipped to detect these jam conditions for the jacking units through an indirect means of current surge. This method is notoriously inaccurate, especially when starting the jacking operation because of the difficulty in differentiating a starting in-rush current from the genuine current surge caused by a jammed condition.

Further difficulties arise when setting a delay to allow the starting transients to die down. This is because the transients vary from motor to motor, as well as from one load condition to another. As a result, protection against jam conditions is usually delayed during starting of motors. In some cases, the starting delay may be critical in protecting the machinery from permanent damage



Jacking systems that employ variable speed drives to control electrical motors also typically use motor currents as jam indicators. However, using the current as the sole indicator is usually insufficient and misleading because the drive can generate high torque upon start without producing surge in current. Also, during running conditions where the torque demand is close to the torque limit, the motor may stall as the variable speed drive tries to control the motor. Such condition may occur without triggering any alarms because the current will be within the normal range.

Methods are available for faster jam detection using a combination of current detection as an indication of load and speed detection to detect abnormal operating speed ranges under various operating conditions, as described by the patents below:

U.S. Pat. No. 4245370 to Baker describes a protection circuit for a vacuum cleaner motor against jamming of the beater brush, which uses a speed signal representing the motor rotational speed for comparison against normal operating speed ranges.

U.S. Pat. No. 4322668 to Trussler et. al. describing a power control method during motor stalling using speed and current signal, to maximize available torque through the entire stalling duration without inflicting thermal damage to the motor.

U.S. Pat. No. 4504881 to Wada et. al. describes a protective circuit for the motor, consisting of a frequency generating circuit corresponding to the motor speed, to detect abnormal decrease in rotation of motor due to overloading conditions.

U.S. Pat. No. 4695779 to Yates describes the protection circuit against stalling for a plurality of operating modes where operating torque are different, consisting of speed signal and current detection. The current is used to detect different operating modes, leading to different time delays for run-up to operating speed. This patent is for uses such as an oil well pumping unit.

U.S. Pat. No. 4547720 to Loudon describes a motor start-stall detection apparatus and method, based on stator and voltage phase difference detection, as a measure of rotational speed.

All the above patents stress on motor protection. The priority is to ensure that when the motor is running at low speeds or stalling, no damage due to overheating occurs.

Furthermore, detection is based on operating conditions for individual motors. Implementation of these methods on a rack and pinion system will result in a slower detection time because at any single time, motion and load conditions vary from one rack to rack. Using a common setting for all motors on a jack-up will result in a compromised time delay. This is complicated by the fact that loading conditions are dynamic during the operations.

In this invention, the philosophy and method for jam detection using motor speed and current monitoring applied to the rack and pinion jacking system is different. When a jam occurs, it is likely that mechanical and structural damage will occur before the motor is damaged due to overheating. The emphasis in this invention is to quickly detect a jam condition, and stop the operation immediately to prevent mechanical and structural damage.

The detection parameters are more extensive consisting of motor speed, rate of change of motor speed, the motor current and the rate of change of motor current. Monitoring and comparison is performed between motors driving the same rack, and not based on a single motor in isolation. As motors on a single rack are closely synchronized, this presents a more efficient method of identifying irregular speeds and accelerations.

However, even with the implementation of the improved method for jam detection into a conventional rack and pinion jacking system, the safety system should be improved further to provide a pre-warning for a jam occurrence.

Jam conditions may and usually develop during the course of operation. The wave motion, wind conditions, considerable loads, differential loading conditions and distance between leg chords contribute to a possibility of misalignment and eventual jamming of the teeth of the rack assemblies. A jacking operation with a leg misalignment may cause considerable damage to both to the leg itself and the leg guides on the hull. The damage will be inflicted over a prolonged period of time before eventually developing into a jammed condition which can then be sensed by the available current and speed jam detection system.

Although the improved system employing motor current surge detection with speed feedback will work well to quickly detect the eventual jammed condition and stop the operation, it desirable and advantageous to have a much earlier warning system to prevent structural damage. The improved jam protection is unable to do this, as it does not have a holistic view and a knowledge base to identify abnormal behavior of a particular set of motors as compared to the other sets. A rack misalignment may induce higher loads on pinions located diagonally but the all the motor current and speed may be well within the operating limits. A leg misalignment relative to the hull may have much higher loads on one of the three racks, but individual motor current and speed will not indicate a jam. Although the existing current and speed feedback system protects the motor and machinery from damage, it does not provide any form of monitoring and protection against structural damage due to irregular motion behavior.

The difficulties for the jacking system as stated above are also applicable for the electrically driven skidding system based on a rack and pinion configuration. Usually the cantilever or drill-floor is driven by a set of 4 to 6 pinions, 2 or 3 on each side. The cantilever structure rests a support frame on the hull and moves along this support frame. The motion cantilever structure is restricted along a single axis by guides on the support frame. Rectification of a jammed condition and misalignment during operation is time consuming and may be damaging to machinery and structure if excessive force is used, especially when positional information of the cantilever relative to the hull is not available.

Patent searches did not show any results that fulfils the above detection requirement for jacking and skidding systems. U.S. Pat. No. 4885698 to Kawasaki provides a means of equalizing pinion loads for a jacking assembly only after the hull has been jacked to operational air gap and engaged in holding mode using the electromagnetic brakes.

The present invention contemplates elimination of drawbacks associated with the prior art and provision of an apparatus for detecting motion irregularities during operations in a rack and pinion system of a jack-up rig that would allow detection of motion irregularities and prevention of structural damage faster than it is possible with conventional systems.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an apparatus for detecting motion irregularities for rack and pinion system.

It is another object of the present invention to provide an apparatus for detecting misalignment, prevent structural damage and provide a warning of a possible jam condition in a rack and pinion elevating system.

These and other objects of the present invention are achieved through a provision of an electromechanical system, which connects a motor that controls rotation of the gear assembly in a rack and pinion system with an electronic assembly that interprets signals received from the motor and a signal indicative of a rotational speed of the gear assembly. An encoder is mounted on a side opposite the input end of the jacking gearbox, or gear assembly. The shaft of the encoder is coupled to the first stage of the gearbox, which is directly coupled to the gearbox-input shaft.

A current transformer that can be installed at one of the incoming phases to the motor monitors the motor current for the jacking assembly. An electronic assembly receives and interprets the electrical signals from the encoder and the current transformer and detects a jamming condition during starting or running of the leg moving assembly.

There is one electronic assembly for each chord to monitor the speed signals and current signals from the motors that are coupled to the particular chord.

The individual chord electronic assembly will transfer information to the central leg electronic assembly to process rack position and load information for the leg.

The system of the present invention allows detecting motion irregularities and potential structural damage in a very short period of time, less than 1 second, thereby saving equipment and structure from permanent damage.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic view showing a jack-up unit with truss legs.

Figure 2 is a plan view of a platform of the jack-up rig showing pinion gear drives for moving the truss legs.

Figure 3 is a detail side view of a pinion assembly shown in Figure 2 taken in the direction of arrows A in Figure 2;

Figure 4 is a detail side view of a pinion assembly shown in Figure 2 taken in the direction of arrows B in Figure 2;

Figure 5 is a detail side view of a pinion assembly shown in Figure 2 taken in the direction of arrows C in Figure 2; and

Figure 6 is a detail view showing an elevating gear assembly and an encoder for detecting misalignment through the rotational speed of the gearbox input shaft.

Figure 7 is a detail view showing the system block diagram for a single rack.

Figure 8 is an overall system diagram showing the complete system for a single leg.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Reference will now be made to the following detailed description, taken in conjunction with the accompanying drawings, wherein like parts are designated by like numerals.

Referring now to Figures 1 - 5, a self-elevating jack-up unit is designated by numeral 10. The jack-up unit 10 is a mobile offshore structure that is used for mineral exploration and production. A typical jack-up unit is provided with a plurality of trussed legs 12, which extend through openings 14 in a floatable hull 16 of the unit 10. Although any number of legs may be used to support the hull 16, for illustration purposes, the jack-up rig shown in Figures 1 and 2 has three such legs 12.

As shown in more detail in Figure 6, a typical leg of a jack-up unit has three mutually parallel chord members 15, and each chord member 15 is provided with a pair of opposing rack members 17, 19 that extend longitudinally along the length of the chords 15. The outward surfaces of the racks 17, 19 are provided with rack teeth (not shown) which engage respective pinions 32 carried by elevating jack units 30.

Conventionally, there is one jack assembly for each chord member 15. Horizontal and inclined braces or trusses 23 rigidly interconnect the chords 15. The chords 15 are located at apexes of the triangularly shaped legs 12, as can be better seen in Figure 2. Of course, the number of chords and the shape of the legs are not limited to the embodiment shown in the drawings.

Each leg 12 is provided with the jacking assemblies 30 for moving the leg vertically with respect to the hull 16. The legs 12 move from a raised position, when the rig 10 is in transit and the legs 12 are supported by the hull 16, to a lowered position, when the legs 12 support the hull 16. The lowered position is illustrated in Figure 1. Each leg 12 may be provided with a spud can 18 for bearing against an ocean floor and for supporting the unit 10.

As the legs 12 are "jacked," the hull 16 is elevated above an anticipated wave action to support the offshore exploration and/or production operations. Conventional

offshore platforms, such as the unit 10, are equipped with a derrick 20 mounted on the hull 16. The derrick may be also mounted on a cantilever structure 22, which extends outwardly from the hull 16, as shown in Figure 1.

The derrick may be positioned for a limited lateral movement to accommodate well drilling in a plurality of locations without changing the position of the legs 12. The platform 10 may be also provided with auxiliary equipment, such as cranes 24, pipe racks, heliport, crew living quarters, etc.

The jack assemblies 30 are retained against vertical displacement by the hull 16. As shown in Figures 2 -5, a typical rig has nine jacking assemblies 30, three assemblies per leg, with one located at each leg chord 15 of the triangularly shaped legs 12. Each elevating jack assembly 30 is secured to the hull within a jack housing 31. Each elevating jack assembly 30 is provided with four pinions 32, which operationally engage teeth of racks 17, 19 associated with the legs 12.

The rack and pinion assemblies are designed to allow a very close tolerance between teeth engaging surfaces of the racks and pinions. These surfaces are designed to mate for better load transfer and stable support of the platform. Since a possibility of misalignment between pinions engaging opposing racks is always present, jamming condition may be encountered during start-up and running of the motor, i.e. when the legs are being moved vertically.

Gear assemblies 52 assist vertical movement of the legs. A gear assembly 52 of the present invention is shown in more detail in Figure 6. The gear assemblies are similar for all rack and pinion jacking assemblies employed in the present invention and only one such assembly is illustrated in detail and described herein.

Each gear assembly 52 comprises a gear wheel 53, which is mounted on an elongated rotating shaft 60. The shaft 60 and the gear wheel 52 is rotated by a power source, such as a hydraulic motor, an electric motor or other power means. In Figure 6, an electrical motor is shown as the power source, coupled at the input end of the gearbox. A power source causes rotation of the pinions 32, moving the legs up or

down in relation to the hull 16, while the jack assemblies 30 remain stationary in relation to the hull.

The shaft 60 extends through a center of the gear wheel 52. An encoder 62 is operationally connected to the shaft 60 through a set of gear trains 64. As shown in Figure 6, the encoder 62 is mounted on a side opposite an input end 68 of the gear assembly 50. A shaft 70 of the encoder 62 is coupled to the first stage of the gear assembly 50, which is directly coupled to the gear input shaft 60.

The encoder 62 measures the rotational speed of the input shaft 68 of the gear assembly 50 during operation of the rack and pinion jacking assembly. The mechanical motion of the input shaft is converted to an electrical signal, which is transmitted to an electronic assembly, schematically shown in Figure 7 and identified by numeral 72.

The electronic assembly 72 also receives signals from a transformer 74, which is schematically shown in Figure 7. The transformer 74 is operationally connected to one of the incoming phases of a motor 76; the transformer 74 monitors the current passing through the motor 76 during starting or running of the jacking systems. It is a normal practice to install the transformer 76 at the motor control center 78 located on the rig 10.

The rack electronic assembly 72 receives the signals from the encoder 62 and the transformer 74 and interprets the signals to determine whether a jamming condition has been created. If such a condition has been detected a signal may be sent to the motor to terminate the supply of current and arrest the rotational movement of the gear assembly 50. By using the encoder feedback, the apparatus of the present invention allows detecting of jamming conditions in a very short period of time, typically in less than one second for normal and pre-load conditions.

In contrast, traditional jacking systems, which utilize the over-current method, have blanking time of 2 seconds, under normal conditions, and 5.2 seconds, under pre-load conditions. The improved accuracy and speed of the detection of the jamming

condition possible with the present invention allows protecting the jacking system from permanent damage.

When the apparatus of the present invention is used with inverter-driven electric motors, it allows detection of motor stalling in a relatively short period of time in addition to the jam condition detection. The problem of motor stalling usually occurs when the torque demand is close to the torque limit. Under such conditions, detection of motion irregularities is even more critical for a series of rack and pinion assemblies requiring strict synchronization of movement. The apparatus of the present invention increases safety features by providing an independent means for detecting unstable loads and speed conditions of the inverter.

When the jacking assemblies move the legs, each rack has a possibility of engaging the teeth of a pinion at different vertical levels. By employing the apparatus of the present invention at each pinion assembly, any possible misalignment of racks relative to pinions and relative to adjacent racks may be checked and corrected before serious misalignment occurs.

As shown in Figure 8, the individual rack electronic assembly 72 for a particular leg will transmit position and load information to the leg electronic assembly 76. The leg assembly will process the relative travel and position of each rack against each other, and the hull position, and determine if the magnitude of misalignment is greater than the permitted limits posed by the leg guides. If the actual misalignment is greater than the allowed limits, the leg electronic assembly will send an alarm signal to the motor control center 78 to terminate the supply of current and arrest the rotational movement of the gear assembly 50. The leg electronic assembly 76 will also utilize the information on the load distribution between the racks received from the individual rack electronic 72 assembly to indicate if the leg structure is undergoing excessive stress, due to misalignment or rubbing against the leg guides. The leg electronic assembly 76 can also be configured to include a display system to show real-time position and load data during the operation.

The present invention provides a holistic system monitoring of the position and load of the rack system relative to the hull and leg guides. This positional

information, coupled with the motor current information is useful for rack and pinion systems, particularly for systems where only small guide tolerance for detection of contact points and loading conditions is acceptable. Continued jacking operations with a misalign leg relative to the hull may lead to excessive wear on the wear plates and possible damage to the legs.

Many changes and modifications may be made in the design of the present invention without departing from the spirit thereof. I, therefore, pray that my rights to the present invention be limited only by the scope of the appended claims.

I Claim:

1. An apparatus for detecting motion irregularities in a rack and pinion assembly of a jack-up platform having a floatable hull and a plurality of supporting legs, the apparatus comprising:
 - a means for vertically moving each of the supporting legs in relation to the hull, said means comprising a gear assembly;
 - a power means operationally connected to said means for vertically moving the supporting legs;
 - a means coupled to said power means for detecting an electrical current supplied by said power means;
 - a means for measuring rotation of said gear assembly;
 - an electronic assembly comprising an encoder operationally connected to a first stage of the gear assembly for comparing electrical signals generated by said means for detecting the electrical current with electrical signals generated by said means for measuring rotation of the gear assembly and for converting mechanical movements of the gear assembly to an electrical signal capable of being interpreted by said electronic assembly, said electronic assembly generating a signal indicative of motion irregularities between said supporting legs and said means for vertically moving the legs.
2. The apparatus of Claim 1, wherein said encoder is operationally connected to a rotational shaft of said gear assembly.
3. The apparatus of Claim 2, wherein said encoder converts rotational movement of said rotational shaft into electrical signals that can be interpreted by said electronic assembly.
4. The apparatus of Claim 2, wherein said encoder is mounted on a connecting shaft, said connecting shaft being coupled to the first stage of the gear assembly.

5. The apparatus of Claim 2, wherein said encoder is mounted on a connecting shaft, said connecting shaft being operationally connected to an input shaft of the gear assembly.
6. The apparatus of Claim 5, wherein said encoder is mounted on a side of said rotational shaft opposite an input end of said gear assembly.
7. The apparatus of Claim 1, wherein said electronic assembly comprises a transformer mounted between said power means and said means for measuring rotation of the gear assembly.
8. The apparatus of Claim 1, wherein said means for vertically moving the supporting legs further comprises a pinion assembly for engaging opposing racks of said supporting legs, said pinion assembly being operationally connected to the gear assembly.
9. The apparatus of Claim 8, wherein said gear assembly is mounted between said pinion assembly and said electronic assembly.
10. An apparatus for detecting motion irregularities in a rack and pinion assembly of a jack-up platform having a floatable hull and a plurality of supporting legs, the apparatus comprising:
 - a means rigidly secured on said hull for vertically moving each of the supporting legs in relation to the hull, said means comprising a gear assembly and a pinion assembly engaging teeth of a rack attached to each of the supporting legs;
 - a power means operationally connected to said gear assembly for rotating said pinion assembly, while said pinion assembly is engaged with the rack of a supporting leg;
 - a current transformer coupled to said power means for measuring the magnitude of electrical current supplied by said power means to said gear assembly;
 - a means for measuring rotation of said gear assembly, said measuring means converting mechanical movement of said gear assembly to an electrical signal;

- an electronic assembly for comparing electrical signals generated by said current transformer with the electrical signal generated by said means for measuring rotation of the gear assembly, said electronic assembly generating a signal indicative of motion irregularities between said supporting legs and said means for vertically moving the legs, said electronic assembly comprising an encoder mounted on a rotational shaft of the gear assembly and on a side of said rotational shaft opposite an input end of said gear assembly, said encoder being capable of converting mechanical movements of the gear assembly to an electrical signal capable of being interpreted by said electronic assembly.
11. The apparatus of Claim 10, wherein said connecting shaft is coupled to a first stage, other suitable installation points, of the gear assembly.
 12. The apparatus of Claim 10, wherein said connecting shaft is operationally connected to an input shaft of the gear assembly.
 13. A method of detecting motion irregularities between in a rack and pinion system of a jack-up rig, comprising a floatable hull and a plurality of supporting legs, the method comprising the following steps:
 - providing a means for vertically moving each of the supporting legs in relation to the hull, said means comprising a gear assembly;
 - providing a power means and operationally connecting said power means to said means for vertically moving the supporting legs;
 - providing a means for detecting an electrical current supplied by said power means to said means for vertically moving the supporting legs;
 - providing a means for measuring rotation of said gear assembly;
 - providing an electronic assembly and connecting said electronic assembly to said power means and to said gear assembly, said electronic assembly comprising an encoder operationally connected to a first stage of the gear assembly, said encoder converting mechanical movements of the gear assembly to an electrical signal capable of being interpreted by said electronic assembly;

- comparing electrical signals generated by said means for detecting the electrical current with electrical signals generated by said means for measuring rotation of the gear assembly and generating a signal indicative of motion irregularities between said supporting legs and said means for vertically moving the legs.
14. The method of Claim 13, further comprising a step of connecting said encoder to an input shaft of the gear assembly.
 15. The method of Claim 13, wherein said encoder converts mechanical movements of the gear assembly to an electrical signal capable of being interpreted by said electronic assembly.
 16. The method of Claim 13, further comprising a step of providing an electrical voltage transformer and connecting said transformer between said power means and said encoder.
 17. The method of Claim 13, further comprising a step of mounting said gear assembly on a rotational shaft and connecting said encoder to a side of said rotational shaft opposite an input end of said gear assembly.
 18. A method of detecting misalignment between adjacent and related racks of supporting legs in a jack-up platform having a floatable hull, the method comprising the steps of:
 - providing a means rigidly secured on said hull for vertically moving each of the supporting legs in relation to the hull, said means comprising a gear assembly and a pinion assembly engaging teeth of each rack;
 - providing a power means and operationally connecting said power means to said gear assembly for rotating said pinion assembly, while said pinion assembly is engaged with the rack of a supporting leg;
 - mounting a current transformer in connection with said power means for detecting an electrical current supplied by said power means to said gear assembly;

- measuring mechanical rotational movement of said gear assembly and converting the mechanical movement into an electrical signal;
- providing an electronic assembly and connecting said electronic assembly to said power means and to said gear assembly, said electronic assembly comprising an encoder operationally connected to a first stage of the gear assembly;
- mounting said encoder on a rotational shaft of the gear assembly and on a side of said rotational shaft opposite an input end of said gear assembly;
- comparing with the encoder electrical signals generated by said current transformer, indicative of the relative loading condition of individual motor and gearbox assembly, with the electrical signal indicative of rotational movement of the gear assembly;
- converting with the encoder mechanical movements of the gear assembly to an electrical signal capable of being interpreted by said electronic assembly; and
- generating a signal indicative of relative vertical alignment between opposing racks of a supporting leg.