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Rotation Sealed Lead-In Unit of Submersible Mechanism

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Abstract

In this paper is reviewing rotation sealed lead-in unit of submersible mechanisms. Reviewable mechanisms are used at sea depth more than 2000 meter. The main idea of research is based on consideration of influence distance between magnetic couplings transmitting rotation through a membrane of a tough box. The emphasis was made on variation magnetic fields depending on membrane width and material. As a result is received a theoretical correlation between transferable torque and depth of submergence. Is shown a rotation sealed lead-in unit design. Is suggested a circular membrane design.

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Keywords: magnetic clutch; circular membrane; planetary gearbox

1. Introduction

In manned and unmanned deep-water units besides main engines, performing predetermined processes, there are also stand-by systems of the mechanical drives. They ensure survivability of the deep-water unit in case of an emergency shutdown of the main power supply [1, 2, 3]. For example, when it is necessary to complete some technological operations using a submersible deep-water drilling rig at sea depths of over 1000 meters in the event of power cut on the cable from vessel or failure of standalone power generator batteries. These operations include raising the drilling tool, keeping its rotation movement going for a while or, in the extreme cases, breaking contact between drilling machine and tool, which will allow raising the machine on board the vessel. Such operations must be carried out by stand-by system with standalone power generator. One of the possible energy supply systems is the use of hydrostatic energy in water depths over 1000 meters.

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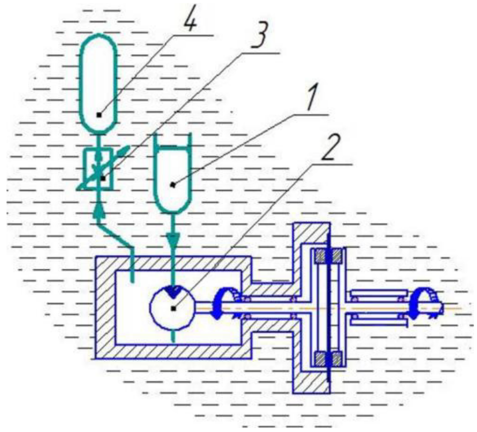


Fig. 1. Rotary drive using hydrostatic pressure

At figure 1 is shows a diagram of the rotary drive using hydrostatic pressure. It includes phase separator 1 of piston or membrane type, hydraulic motor 2, located in a tough box, controlled regulator of working fluid flow 3, tough box cylinder 4. Phase separator isolates hydraulic system working fluid from seawater. At the same time working fluid pressure is equal to the hydrostatic pressure at the given depth of the sea. As we immerse at the required depth, working fluid pressure stays equal to the ambient pressure, pressure in the cylinder 4 remains constant and is equal to atmospheric pressure. Hydrostatic pressure of the sea multiplied by the volume of the cylinder is equal to the stored energy. When we turn on the flow controller 3 because of the differential pressure the working fluid from separator 1 enters cylinder 4 through hydraulic motor 2 and thus accumulated hydrostatic energy is converted into mechanical energy of rotation of the hydraulic motor shaft. A special feature of such a system is the fact that it is necessary to transmit torque from the hydraulic motor, located in a tough box at atmospheric pressure into an environment with high hydrostatic pressure.

One way to transmit the rotational movement, while ensuring sealing (hereafter "rotation sealed lead-in unit") is the use of magnetic clutch based on the permanent magnets through the separating membrane. Examples of application of such mechanism with pressure difference less than 2 MPa are shown in publications [4, 5, 6, 7].

With increasing depth of immersion, the pressure on the membrane increases and the estimated value of the thickness of the membrane by strength may reach critical values for the magnetic interaction. The thickness of the membrane is a determining factor in the choice of the distance between the couplings and the permissible value of the transmitted torque.

2. Proposed solution

The main idea with this paper is to justify the choice of geometrical dimensions of the membrane depending on pressure (depth of immersion) and their effect on the transmitted torque, as well as the choice of the constructive scheme of the sealed lead-in.

The solution of the problem involves the following steps:

1. Determination of analytical expression of the clutch torque (force that prevents slippage) of the coupling and identification of how clutch torque depends on the gap between couplings;
2. Determination of the stress distribution in the plate and in the design of thin-walled shell, at which the maximum torque transfer is achieved without destroying the walls of the shell itself.

To determine the force between two magnets it is necessary to determine the value of the magnetic field at each point of the space between the magnets. Since magnets are a complex monolithic structure, it is necessary to make some assumptions in consideration of their interaction in a magnetic field. The first and basic assumption is isotropy of substance, i.e. uniformity of physical properties throughout the material volume. Also in electromagnetism, namely in the magnetic interactions, in most cases we do not consider the material, but the currents of materials. Thus, any material can be represented as the sum of the cyclic currents of various configuration, which may be reduced to a current loop. But if the main parameter of the magnetic current loop is the current (I), in case of the magnet it is magnetization (J). Therefore it is necessary to go with the help of the formula from magnetization by volume to the current along the contour.

According to the method of calculation of magnet interaction in [6], here we have a graph of dependence of the relative torque from angle of deviation of the magnets (see Fig.2) while keeping the same magnetization J and gap S.

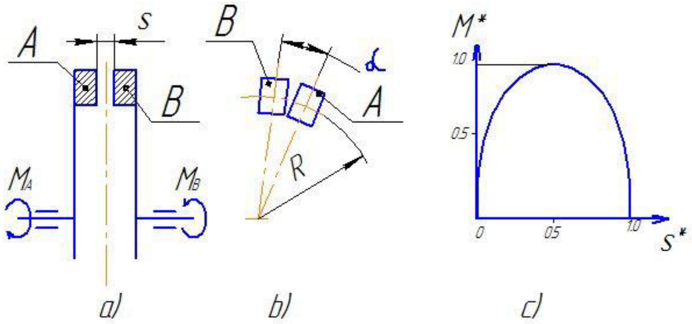


Fig. 2. Dependence of relative torque from angle of deviation of the magnets.

Here M*=M_{max}/ M – relative torque, M_{max} – maximum torque at the moment of out of sync;

α* =α_{max} / α, α_{max} – maximum angle between the magnets corresponding to the angle of out of sync.

When choosing a rated torque of clutch M_{nom}, we use safety factor at the transmitted torque K_m =M_{max} /M_{nom}. Safety factor may vary depending on the working conditions of the mechanism and can be set between K_m=2,0…1,05. As you can see on the Fig. 2c the dependency of torque from angle of deviation is not linear and at some points near the rated torque may have squared dependence. As we increase the gap between the ends of coupling, magnetic resistance in the circuit flux also increases and therefore the angle of out of sync decreases. This leads to the cubic dependence of the transmitted torque from the gap.

M_{nom}=K_k/S^3,

where K_k – constructive factor.

The manufacturers of magnetic clutches like [7] regulate the gap between the clutches between 4..6 mm. If separating membrane is used, this gap is increased by the thickness of the membrane, which significantly decreases the transmitted torque.

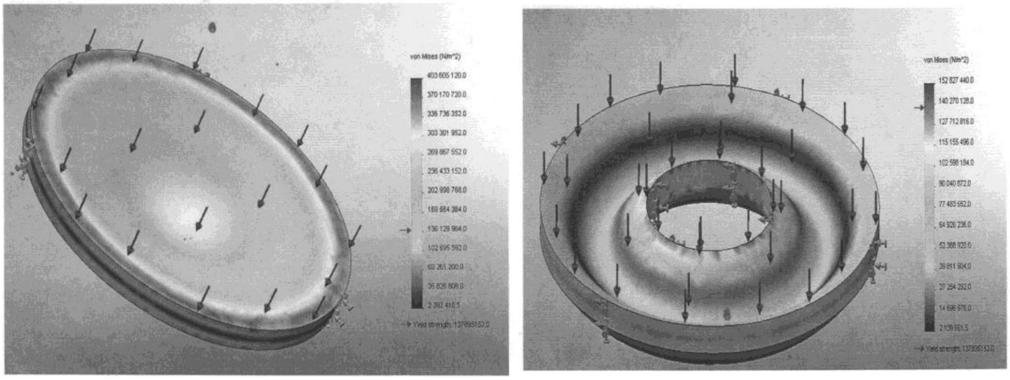
In order to get the required torque it is necessary to choose shape and material of the membrane carefully considering working conditions. Since magnetic field is moving, superficial (eddy) currents are induced, the shell will get heated which in turn will cause the strength characteristics of the material to decrease. The material of the membrane should also be corrosion-resistant. Titanium alloy and many composites are the examples of such materials. For example titanium alloy Ti-8-1-1 has a yield point of 1070 MPa and ultimate strength of 1180 MPa. Composite AS4D has the ultimate strength of about 2413 MPa. At the same time they demonstrate low conductivity and almost don't have any influence on magnetic field.

It is possible to increase the transmitted torque by increasing the radial size of the clutch, but this will lead to the increase of tension in the attachment points of membrane. However, with increasing pressure difference between environmental and one inside solid case of hydraulic motor, membrane undergoes elastic bending deformation, which makes it necessary to increase the thickness of the membrane, and therefore, increase the distance between the end faces of the couplings of the magnets. In turn, the value of the maximum transmittable torque decreases in almost cubic dependency with increase of distance between the end faces of the couplings (2). This dependency requires the establishment of reliable methods of calculating the strength and elasticity of the membrane and informed choice of materials.

In engineering practice, such membrane is calculated as thin-shell structure and during the application of external pressure load the highest value of the bending moment will be at the clamped end while maximum deflection will be in the middle of the plate. With increasing pressure on phase separator and the increase in thickness of the membrane, the use of magnetic clutch becomes ineffective. It is possible to decrease strain and deformation through changing the design of the membrane.

3. The real system

One of the possible designs is to connect central part of the wall with fixed axis inside the shell and to make the wall thicker in all areas except for the surface through which magnets interact. While doing the strength calculations solid membrane is replaced by circular membrane clamped by outer and inner circumference. This can significantly reduce the stress in the bedding points and reduce deformation.



a) b)

Fig. 3. Results of stress and deformation calculations of (a) tough membrane and (b) circular membrane.

Figure 3 demonstrates the results of calculating tension and deformation of the solid membrane (a) and circular membrane (b). It is obvious that given the same load tensions at the attachment points of the circular membrane are significantly lower.

However, while developing this design we face insurmountable difficulties associated with central rotation of the couplings at the phase separation. It is possible to overcome this challenge by combining rotation sealed lead-in unit and planetary gear reducer as a single mechanism.

The structural layout of this mechanism is shown in the figure 4.

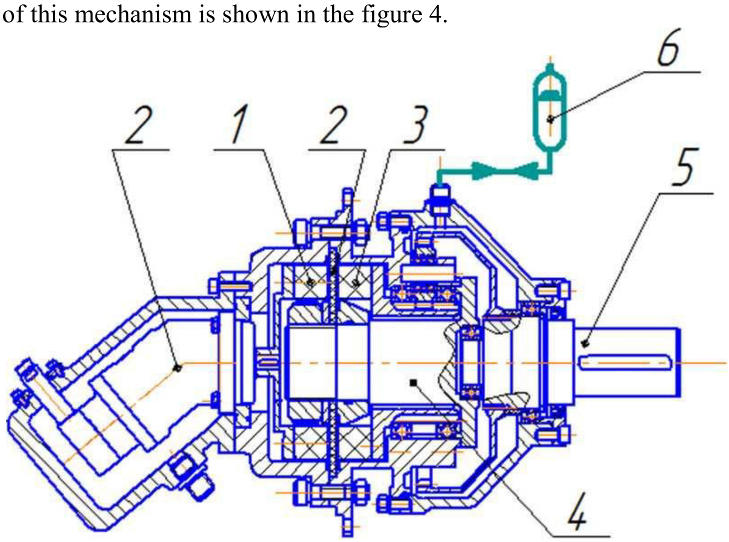


Fig. 4. Rotation sealed lead-in unit and planetary gearbox combined as a single mechanism.

Drive coupling 1 mounted on hydraulic motor shaft and through circular membrane 2 transmits the torque to the driven coupling 3. Planetary gearbox is made according to the scheme 2k-hc with stopped carrier. In the carrier there is a driven coupling (mounted with ball bearings) with teeth cut of the reduction gear central wheel. Membrane 4 is fastened to the shaft 5 along the inner circumference, which in turn rests on the carrier. Thus, the membrane is protected against axial movement and tightness is ensured at the phase separation. Rotation from the driven coupling is transmitted via satellites to a central wheel with internal teeth and further to the output shaft 6. Gear housing is filled with a liquid lubricant and is separated from the environment with seal of rotation with the pressure 0.1 MPa. In order to protect reduction gear against flooding and create positive pressure up to 0.05MPa there is a weight-loaded hydraulic accumulator 7 mounted.

4. Expected results

Comparative modeling and calculation of the stress and deformation of the solid and circular membranes conducted in the Solidworks, showed that at equal pressure loads the maximum stress and deformation of the circular membranes is about 1.5-2 times less than that of the solid.

Conclusions

In this paper is received a theoretical correlation between transferable torque and depth of submergence. Is shown a rotation sealed lead-in unit design. Is suggested a circular membrane design which with a planetary gearbox allow increase transmitted torque in 1.5-1.8 times. This circular membrane at equal loading pressure allow decrease tension in 1.5-2 times in compare to not-circular.

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