

An electrical submersible pump

Invention description

The proposed invention relates to high-speed electrical submersible pumps used for hydrocarbons production from oil wells with high concentration of solids.

Pump application is defined as a high-speed application if the pump is spinning with the rate over 4500 RPM. Formation solids average concentration in the production flow from Russian-field wells is 0.2 g/liter. In case of heavy oil production this parameter can be even much higher. The concentration of proppant flowback in the production flow can reach concentrations as high as 1 g/liter immediately after fracturing. A high rotational speed combined with high solids concentration in the production flow causes accelerated erosion wear of pump stages. Solids being trapped inside the stage's small gaps between spinning and stationary components produce abrasion in the stage material. As a result, the pump efficiency is decreasing. Stages wear also leads to an increase in dynamic load for journal bearings. Accelerated wear of radial bearings may be a cause for pump premature failure. The theory of erosion teaches that erosive wear rate is proportional to the particles velocity squared. For example, the pump rate growth from 3500 RPM to 7000 RPM will result in 4-times growth in the stages erosion wear rate. With current oil industry trends to increase the production rate through operating of pumps at higher RPM, the erosion-protective elements became a vital feature for petroleum pump design.

The patent RU2,018,716 discloses a multistage centrifugal pump comprising a housing, guide vanes, shaft with impeller, intermediate spacers. The designed details has protective coating from wear-resistant material deposited, at least, in the places of shaft bending under the load exerted by intermediate bushings and guide vanes. Protective coating for

opposite surfaces of guide vanes and spacers are made of superhard material from the group of self-fluxing chrome-nickel alloy and/or superhard nickel-aluminum material.

The shortcoming of this design is a low resistance to abrasive impact by particles suspended in the fluid.

The patent RU2,132,000 is known for a multistage centrifugal pump comprising a housing, guiding apparatuses installed inside the housing through end and intermediate bearing supports, a shaft with alternative arrangement of impellers and spacers. Every impeller has an annular support of lower disk for delivering of axial loads to the housing while pump operation. Every intermediate spacer is made from two ring U-like items telescopically mated to each other. They have holes in the base, so one U-shaped item is tightly fixed between the guiding apparatuses, and axial mobility of another U-shaped item is provided by the size of the longitudinal groove in the immobile item and the peg matched to the groove of immobile item. The base of the said item has two lugs, one is required for contact with annular support of the impeller above, and another lug is required for closing of the ring-like cavity created by the external cylindrical surface of the protective bushing and the inside wall of immobile U-shaped item, and external side of the mobile U-shaped item. This ring-like cavity accommodates an elastic material, e.g., fluoroplastic or its composites.

The shortcoming of this pump is complex design and low stability to impact of abrasive particles suspended in the pumped fluid.

The closest analog to the disclosed invention is the design of multistage submersible centrifugal pump (authorship certificate SU1,763,719). This pump consists of a cylindrical housing with many stages. Every stage is installed on the shaft with axial freedom for the impeller (with hub) and the diffuser, that includes the housing-fixed vaned disk with a central orifice and vanes on the butt faced by the back to the impeller end, and an external disk with a hub. At that, surfaces of the orifice of the vaned disk and the hub of the external disk produce an annular channel. At least part of diffusers are equipped with intermediary spacers

making the inside surfaces of the hubs. The diffusers with intermediary spacers are equipped with damping O-rings; they are equipped with windows and made from an elastic material; the rings are laid into the inlet annular channels.

The drawback of this pump is low resistance to abrasive particles suspended in the pumped fluid.

The technical task for the invention is development of a new design of submersible pump.

The technical result achieved by applying a pump with disclosed design is a longer service life.

To achieve the said technical result, an electric submersible pump is designed. The pump comprises: a housing with a head and a base, a compression nut, a shaft installed on a journal bearing, stages of impellers and spacers installed on the shaft, set of diffusers installed on the housing, wherein the diffusers and impellers are manufactured from a ceramic material. The preferable design has metal spacers between the diffusers, wherein the length of the diffuser spacer between the contact surfaces equals the distance between the impeller spacers.

In preferable embodiment, the diffuser spacer made as an element with essential rigidity in the axial direction but flexible for bending, the impeller spacer has a protrusion, and the ceramic impeller has a mating slot, and besides, has a rounded axis-directed slit that passes the whole inner diameter of the impeller. In the preferable embodiment, the protrusion of the impeller spacer has a flexibility enough to hold a torque. For longer service life of the submersible pump, the metal impeller spacer may be coated with an abrasive-resistant material. Two matching surfaces of stages are divided by a layer of damping material, usually an elastomer. A diffuser spring sleeve with high rigidity in axial direction may be installed between the diffuser stack and the head. In this case another similar spring sleeve (with smaller size) is installed between the shaft nut and the impeller stack.

The disclosed invention is illustrated by the following drawings. The pump section general view is shown in Fig.1. The stages detailed construction is shown in Fig.2. Cross section A-A' is shown in Fig.3. Impeller spacer connection with the impeller is shown in Fig.4. The pump diffuser spring sleeve and the impeller spring sleeve are shown in Fig.5 and Fig.6. One of the possible designs for the diffuser spacer is shown in Fig.7.

The erosion-resistant pump section design (see Fig.1) consists of the following components: housing 1, shaft 2, head 3, base 4, diffusers 5, impellers 6, journal bearings 7, impeller spacers 8, diffuser spacers 9, diffuser spring sleeve 10, impeller spring sleeve 11, compression nut 12, and torque spline coupling 13.

The diffusers stack is compressed inside housing 1 between head 3 and base 4. The compression force magnitude is several tons. The compression force required value is based on criteria of gaps elimination between contact surfaces and providing enough friction for preventing diffusers turning inside the housing. Impeller stack is compressed by means of nut 12 on shaft 2. For impellers stack compression force magnitude requirement is much lower – only couple kilograms. A lower compression force in case of impeller stack is explained by the fact that there is a special torque transmission feature (explained below in the patent description), constructed between shaft and each impeller. Consequentially, the compression force for impeller stack should be just sufficient enough to close the gaps between impeller and spacer contact surfaces.

Diffusers 5 and impellers 6 are built entirely from ceramic material. Aluminum oxide (Al_2O_3) can be used as ceramic material for stages fabrication. Aluminum oxide has excellent erosion resistant properties and

will allow pump stage to last for a long time in presence of production solids without pump head and efficiency deterioration.

Thermal expansion is one of the main issues to be addressed in the pump construction with monoblock ceramic stages. This issue is due to the fact that there is a significant difference in thermal expansion coefficients for steel and ceramic. The thermal expansion coefficient for aluminum oxide ceramics is approximately two and a half times less than for steel. If, for example, the pump section is exposed to downhole temperature $+120^{\circ}\text{C}$ (typical for Russian fields), then two main problems will be encountered:

1. Lost of compression force for impeller and diffuser stack.

For a pump section with the housing length of 6 m assembled at room temperature $+20^{\circ}\text{C}$, the new downhole temperature of $+120^{\circ}\text{C}$ creates thermal a expansion resulting in length difference between housing (from carbon steel) and ceramic diffusers stack about 4 mm. Obviously the diffusers stack compression force declines significantly and, depending on the initial stack compression force and housing elongation during assembly, the preloading force drops significantly (approximately by 70%) and the diffusers can become loose.

2. Lost of the gaps between diffuser and impeller stages.

In a pump complete assembly including the electric motor and the protector, each impeller downthrust washer is barely touching the mating surface on the diffuser and equal upper gap is maintained between each impeller and diffuser (upthrust washer can be positioned either on impeller or diffuser dedicated surface/groove). The upper gap value for each stage is identical within tolerance limits and for most pumps this gap is maintained in the range of 1-1.5 mm. Even a slight difference in the overall length between diffusers and impellers stacks under the downhole

temperature conditions causes elimination of the upper gap and growth of the lower gap for a significant number of stages. As a result, a pump assembly, even being properly assembled and shimmed at the shop or surface conditions, will end up with a jammed impellers/diffusers stack under downhole conditions and the pump will be stalled.

Another important issue to be addressed in the proposed design is ceramic stages bending and impact stresses reduction and damping. The ceramic material has high compressive strength but limited flexural strength and sensitive to impact loads. Bending stresses will be induced in stages during pump handling/shipping operations. Impact loads will be generated when diffuser/impeller surfaces touching each other in overlapping areas with small gaps, and during rotation transmission from shaft to impellers.

The proposed pump construction eliminates the above described thermal expansion, bending, and impact loads issues.

Thermal expansion issue (problem number one) is solved by means of a spring type design of the spacer sleeve 10 for diffusers stack and the spring type design space sleeve 11 for impellers stack shown in Fig.5 and Fig.6. Sleeves have tangential overlapping slots 24 and 25 arranged in a pattern shown in Fig.4 and Fig.5. Multiple slots arrangement converts this spacer sleeve into a spring with high stiffness (high ratio of compression force to deformation). In the proposed pump construction, spring sleeve 10 is placed between the upper diffuser and pump head 3 (see Fig.1). Spring sleeve 11 is placed between the upper impeller and shaft nut 12 (see Fig.1). The proposed sleeve construction maintains a sufficient compression force for impellers and diffusers stack and also handle the difference in thermal expansion of the shaft and the housing. Elastomer ring 17 (Fig.2) with rectangular or round cross-section is placed the groove at the outer surface of ceramic diffuser. The friction force, originated by contact of the elastomer ring, diffuser, and housing, helps in preventing

diffusers turning inside the housing. This makes allowance for loss of friction torque between the diffuser faces due to thermal expansion.

Thermal expansion issue (problem number two) is solved by introducing a steel spacer 9 between diffusers 5 (see Fig.2) with the length equal to the impeller spacer length.

$$L(\text{spacer diff}) = L(\text{spacer imp})$$

The proposed construction the temperature-induced extension is the same for stacks of diffusers and impellers. As a result, stages adjustment is not lost and stays the same irregardless of the downhole temperature.

Important aspect of the proposed pump design is transmission of torque from shaft 2 to impellers 6. In conventional pump sections with cast iron stages the key – groove connection is used for torque transmission. A long rectangular-shaped key is retained in the shaft groove and each impeller bore has a matching slot. In case of an impeller built entirely from ceramic, this design cannot work properly. Shock loads are transmitted though the metal key and destroy the ceramic material of the groove. The key size and the impeller hub dimensions prevent making a robust key-groove connection. In the disclosed design this issue is by arranging of another mechanism for torque transmission (see Fig.2 and Fig 3). The torque from shaft 2 is transmitted through conventional rectangular-shaped key 15 to steel spacer 8. The torque from spacer 8 is transmitted to impeller 6 through protrusion/slot connection. Impeller spacer protrusions 14 are mating slots 23 on the impeller hub face (Fig.4). The materials thickness available through the connection ensures robust torque connection between steel and ceramic components. To dampen the impact of chock load while torque transmission, the protrusions 14 have a flexible feature due to matching configurations 21 shown in Fig 4.

To make easy the key allocation, the impeller inner surface has a rounded groove 16 (see Fig.3).

To protect the diffuser from bending load, the spacer 9 is made strong in axial direction and flexible in transverse direction. In other terminology, "hinge element" is placed between the diffusers. One of design variants of the spacer is shown in Fig.2. Spacer 9 (Fig.2) has a machined piece with a reduced diameter. This design reduces the bending rigidity while keeping axial rigidity at the same level. Another version of fabrication of the diffuser spacer is shown in Fig.7. In preferred embodiment, the spacer is made from 3 rings: the central ring has a higher axial length to be rigid to support local axial loads at 90 degree locations. The two outer rings will probably have a slightly smaller axial extend. The outer rings are connected to the central ring only via two metal zones (uncuts) at 180 degree from each other. It should also be noted that the metal zone of the top ring are at 90 degrees from the metal zone at the other ring. With such a design, the ring is extremely rigid in compression. But its two external face can be bent in any direction.

One of the way achieving this is also by placing undercuts 18 (Fig.2) through the diffuser spacer middle area.

To prevent stage features damages from impact loads, elastomer layers 19 and 20 are placed on diffuser surfaces (Fig.2).

Impeller spacer 8 outside surface is built from abrasion resistant material. The surface layer can be represented by tungsten or silicone carbide material or by ceramic material as well. Each diffuser hub and impeller spacer pair also acts as a radial bearing with wear-proof surfaces.

The above described pump features allow to construct an erosion-resistant electrical submersible pump from monoblock ceramic stages.

We claim:

1. An electrical submersible pump comprising a housing with a head and a base, a compression nut, a shaft installed on a journal bearing, impeller stages which are installed on the shaft, a housing holds diffusers, wherein spacers are installed between impeller stages and diffusers and impellers are manufactured from a ceramic material.
2. The pump as in claim 1, wherein metal spacers are placed between diffusers, wherein the length of spacer between the diffuser contact surfaces is equal to the impeller spacer length.
3. The pump as in claim 2, wherein the diffuser metal spacer is constructed in form of a sleeve rigid in axial direction and flexible in bending.
4. The pump as in any one of the previous claims, wherein the impeller metal spacer has protrusions at one side, the ceramic impeller has matching slots and one rounded axial slot through the inside diameter surface.
5. The pump of claim 4, wherein the impeller spacer protrusions are flexible for torsion load.
6. The pump as in any one of the previous claims, wherein the impeller metal spacer has an outside layer made from abrasion resistant material.
7. The pump of claim 1, wherein an elastomer compound in a form of a rectangular or O-ring is placed into a groove on the ceramic diffuser outside surface.

8. The pump as in any one of the previous claims, wherein a layer of soft compound is placed between stages overlapping surfaces.
9. The pump as in claim 8, wherein polymeric elastomer is used as the soft compound.
10. The pump as in any one of the previous claims, wherein a sleeve with essential rigidity in axial direction is placed between the diffuser stack and the head and a similar sleeve of essential axial rigidity of smaller size is placed between the shaft nut and the impeller stack.