Case Study Cyber Physical Production System Using AM

SINGLE SCREW PUMP

Group 14

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Abstract

Screw pumps are positive displacement pump widely used in various industries. There are mainy two types of screw pumps, single rotor and multiple rotors. This paper emphasizes primarily on single screw pump and their characteristics. A single screw pump uses a single helical rotor and double helical stator to move fluids axially. Based on their geometric theory focusing on design characteristics, a systematic study has been presented in this report. The advantages,disadvantages of single screw pump and some alternate solutions are also discussed briefly. Information gathered from this research will be used for parametric modeling of the single screw pumps in IceSL with the help of the Lua script. Moreover, an educational video will be compiled to elaborate on their functional characteristics.

Schraubenpumpen sind Verdrängerpumpen, die in verschiedenen Branchen weit verbreitet sind. Dort Es gibt hauptsächlich zwei Arten von Schraubenpumpen, Einzelrotor und Mehrfachrotoren. Dieses Papier betont Größen hauptsächlich auf Einspindelpumpen und deren Eigenschaften. Eine einzelne Schneckenpumpe verwendet ein einzelner spiralförmiger Rotor und ein doppelt spiralförmiger Stator, um Flüssigkeiten axial zu bewegen. Basierend auf ihren Ge- metrische Theorie mit Fokus auf Designmerkmale wurde eine systematische Studie vorgelegt in diesem Bericht. Die Vorteile, Nachteile der Einschneckenpumpe und einige wechseln sich ab Auch Lösungen werden kurz besprochen. Aus dieser Forschung gewonnene Informationen werden verwendet zur parametrischen Modellierung der Einschneckenpumpen in IceSL mit Hilfe von Lua Skript. Darüber hinaus wird ein Lehrvideo zusammengestellt, um deren Funktion zu erläutern Eigenschaften

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1 INTRODUCTION

Screw pumps are a special type of rotary positive displacement pump in which the flow through the pumping elements is truly axial. As the screws rotate and mesh, the liquid is carried between screw threads on one or more rotors and is displaced axially. The screw pump, with its distinctive axial flow pattern and low internal velocities, has significant advantages in many situations where liquid agitation or churning is undesirable. In all other rotary pumps, the liquid is forced to travel circumferentially. Screw pumps are used in a variety of industries, including the military, the marine industry, and utilities[3]. Chemical processes, the petroleum and crude oil sectors, marine cargo, industrial oil burners, lubricating oil services, power hydraulics for machinery, and fuel oil services.

In general, there are two types of screw pumps: single rotor and multiple rotors. The progressive cavity or single-screw pump (Figure1.1) features internal threads on the stator (rotor housing or body) that mesh with the eccentric rotor thread that is offset from the axis of rotation.There are numerous layouts and designs for multiple-screw pumps, Igor J Karassik discusses more about it in his book [1] Each uses a single driven rotor in a mesh along with one or more sealing rotors. There are two standard variants offered by several manufacturers: single-end and double-end construction.[1]

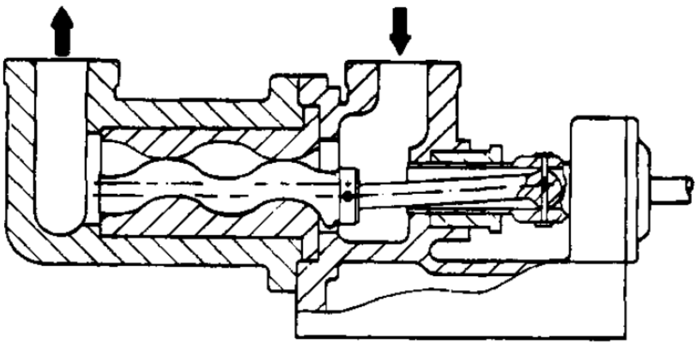

Figure 1.1: Single screw pump [1]

The single screw pump functions on the Archimedes screw principle in terms of geometry as mentioned in Pumpen für Abwasser- und Kläranlagen [6] . A series of sealed cavities are formed between the rotor and stator thanks to the special geometry of the helical rotor. Each chamber moves from the pump's inlet end to its output end as the rotor revolves, bringing the fluid with it. The pump can handle fluids with high viscosities or those containing particulates without harming the fluid or the pump itself because to the shape of the helical rotor.The geometry of a single screw pump has a significant impact on its efficiency.[1] The pump's flow rate, pressure, and overall performance are all influenced by the rotor's pitch, rotor and stator diameters, and the number of helix turns.The single screw pump's shape makes it possible to produce a fairly constant flow rate even when the pressure varies, which is one of its main benefits. The reason for this is because the flow rate is precisely proportional to the rotor's rotational speed because the cavities the rotor and stator produce retain a constant volume during the pump's operation.

Single screw pumps are appropriate for applications where a stable flow rate is crucial since they are designed to give a continuous flow with no fluctuation. They can draw materials or fluids into the pump without the need for external priming because they are self-priming.

Some common purposes of single screw pumps include:

1.Fluid transfer: Single screw pumps are frequently used to move fluids between tanks, vessels, and other process machinery.

2.Metering and dosing: Single screw pumps are ideal for applications that require accurate metering and dosing of fluids or materials.

3.Wastewater treatment: Sludge management, de watering, and thickening are accomplished in wastewater treatment facilities using single screw pumps.

4.Food processing: For handling thick and delicate fluids like milk, honey, and chocolate, single screw pumps are utilized in the food and beverage industry.

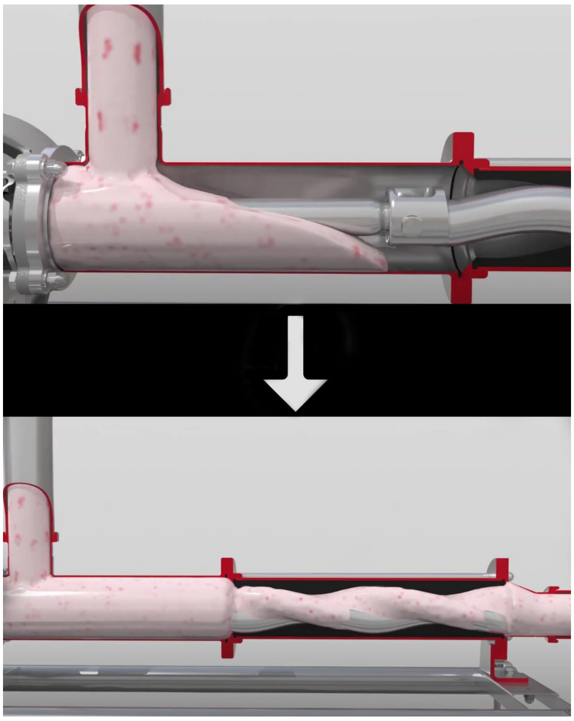

Figure 1.2: Pumping high viscous food material[13]

5.Chemical processing: A variety of liquids, including acids, solvents, and fuels, are transferred and measured using single screw pumps in this business.

A single screw pump is designed to move fluids and materials reliably and effectively in a variety of industrial, commercial, and municipal applications.

This paper emphases primarily on the geometric characteristics of Single screw pump. With a mathematical approach, the geometric models of the stator and rotor are investigated. The design of single screw pump is best suited for moving fluids axially, without churning or agitation. It is expected that this study should be helpful in the designing and parametrical modelling of the Single screw pump in IceSL with the help of Lua script.which can be used in additive manufacturing of the machine element. Moreover to compile an educational video elaborating the functional characteristics of the single screw pump.

2 DESIGN AND WORKING

2.1 Design

The pump consists of a cylindrical housing or stator with one or more internal threads, and a helical rotor that fits inside the stator and rotates to create a seal and move the fluid or material through the pump. The construction of a single screw pump typically includes the following components:

1. Stator: The stator is the fixed outer housing of the pump and is typically made of steel or other durable materials. The stator has a helical internal thread that matches the helix of the rotor, and this thread creates a seal with the rotor to prevent fluid or material from leaking back out of the pump.

2. Rotor: The rotor is the rotating component of the pump and is typically made of stainless steel or other materials that are resistant to wear and corrosion. The rotor has a helical shape that matches the thread of the stator, and as it rotates, it creates a series of cavities between the rotor and stator that move the fluid or material through the pump.

3. Drive shaft: The drive shaft is a solid shaft that connects the rotor to the power source, typically an electric motor or engine. The drive shaft is supported by bearings at both ends to reduce friction and wear.

4. Seals: Seals are used to prevent fluid or material from leaking out of the pump at various points. These seals can include mechanical seals, packing glands, or lip seals, depending on the application and the type of fluid or material being pumped.

5. Inlet and outlet ports: The inlet port is where the fluid or material enters the pump, while the outlet port is where the fluid or material exits the pump. These ports can be located on either end of the pump or on the side, depending on the application and the pump design.

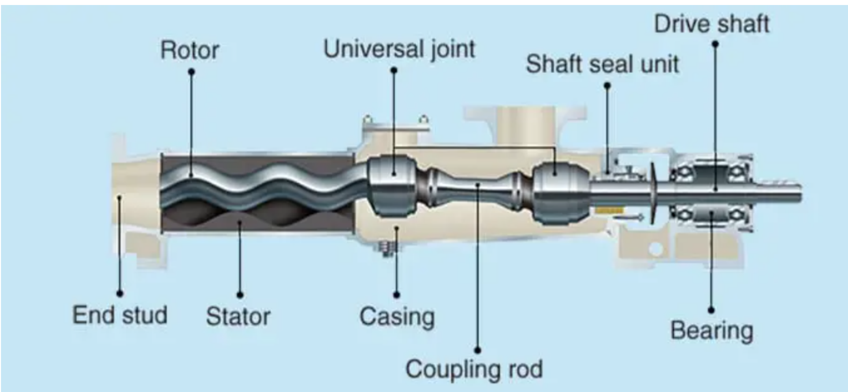

Figure 2.1: Progressive cavity pump definition parts components[14]

2.2 Working

The working principle of a single screw pump is based on the positive displacement of fluid or material through a rotating screw or rotor that fits inside a fixed stator or housing. The following steps describe the working of a single screw pump:

1. Inlet: The fluid or material enters the pump through the inlet port and fills the space between the rotor and stator.

2. Sealing: The threads of the rotor and stator interlock to create a seal between them, preventing the fluid or material from leaking back out of the pump.

3. Rotation: The rotor rotates, and as it does so, it creates a series of cavities or chambers between the rotor and stator.

4. Movement: The rotation of the rotor moves the cavities from the inlet port to the outlet port, carrying the fluid or material with them.

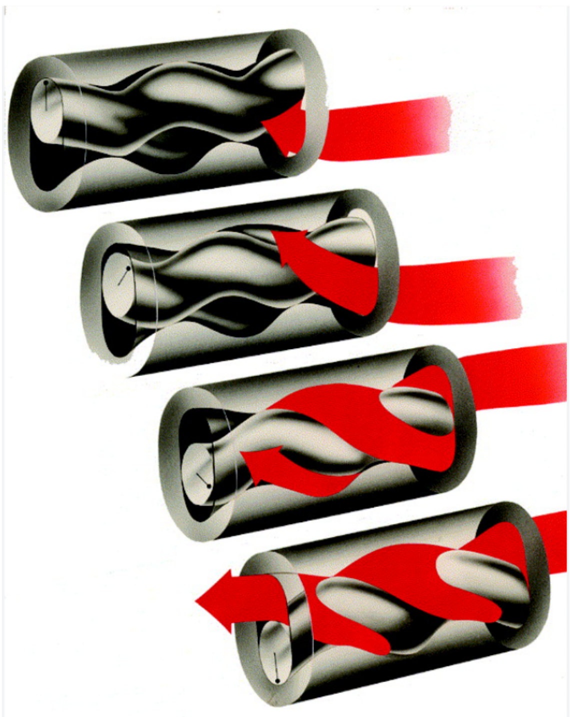

Figure 2.2: Movement of fluid through the pump[5]

5. Discharge: As the cavities approach the outlet port, the pressure increases, and the fluid or material is discharged from the pump through the outlet port.

6. Repeating: The process is repeated, with the rotor continuing to rotate and create new cavities that move the fluid or material through the pump.

3 GEOMETRICAL AND MATHEMATICAL MODELLING

The operating principle of the progressive cavity pump is based on two theories: 3-D vector and Hypocycloid theories.

3.1 3-D vector theory

One point in a three dimensional space can be determined by a position vector P(x, y, z) in a rectangular coordinate (x, y, z) as described in the Figure3.1. The position vector $\vec{r}(s)$ is specified by two components; namely the magnitude (the distance from the origin O of the coordinates to the point P) and the direction (from the origin O to point P). The arc length between the O and P is defined as (s).[16][7][17]

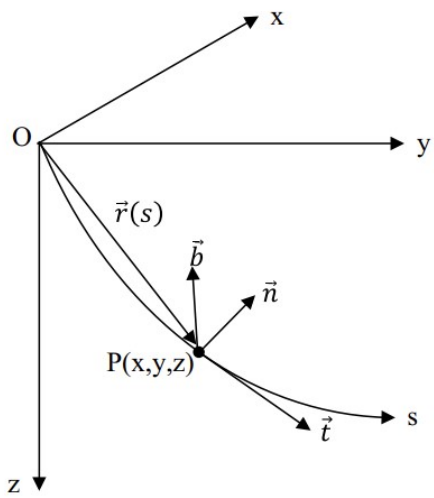

Figure 3.1: A three dimensional space curve[17]

In a 3-D space, the position vector of this curve can be expressed as,

$$\vec{r}(s) = x(s)\vec{i} + y(s)\vec{j} + z(s)\vec{k} \tag{1}$$

The first derivative of position vector with respect to the arc length (s) gives:

$$\vec{T}(s) = \vec{r}'(s) = \frac{dx(s)}{ds}\vec{i} + \frac{dy(s)}{ds}\vec{j} + \frac{dz(s)}{ds}\vec{k} \tag{2}$$

The tangent unit vector is defined as:

$$\vec{t}(s) = \frac{\vec{T}(s)}{||\vec{T}(s)||} \tag{3}$$

The definition of the tangent vector and the unit normal vector will be applied to design PCP pumps.

3.2 Hypocycloid Theory

The principle of the hypocycloid is the original contour of cross section of a PCP pump. In geometry, a hypocycloid is a special plane curve generated by the trace of a fixed point on a small circle (generator circle), that rolls within a larger circle (base circle). Unlike the cycloid, the hypocycloid rolls within a circle instead of along a line. The main design principle of PCP is that the stator has one lobe(K) more than the rotor and every gear of the rotor must always be in contact with the inner surface of the stator. This paper focuses on the ratio of stator to rotor of 2:1, such that the stator has two lobes and rotor has one lobe. The study of multi-lobed pumps have been discussed in[16] To understand this in more detail, consider two circles, If the smaller circle has a radius of r, and the larger circle has a radius of R = Kr, then the parametric equations for the curve in 2D can be given as,

$$\begin{aligned} x(\theta) &= r(K-1)cos(\theta) + rcos[(K-1)\theta] \\ y(\theta) &= r(K-1)sin(\theta) - rsin[(K-1)\theta] \end{aligned} \tag{4}$$

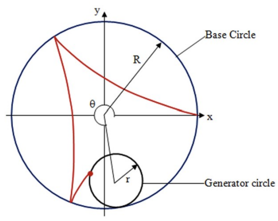

Figure 3.2: Method of generating the hypocycloid.[15]

As shown in Figure 3.2, θ is the angle between the x-axis and the line connecting two center points of the two circles (generator and base circles). If K is an integer, then the curve is closed. if K = 2, the diameter of the small circle is half of the diameter of the large circle and the hypocycloid is a line with its length equals to the diameter of the large circle, it is called 2-lobe hypocycloid. In general, when the value of K is an integer, it is equal to the number of lobes of the hypocycloid. Figure3.3 shows a hypocycloid of K = 2.

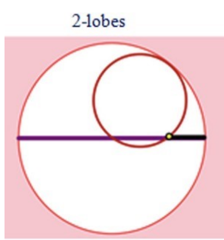

Figure 3.3: Hypocycloid of K=2[17]

Any given point on this hypocycloid can be described by using the Eqs 4 and where θ changes from 0 to 360 and x and y are the two components of the position vector $\vec{r}(\theta)$ in 2D.

The first derivative of $\vec{r}(\theta)$ gives the tangent vector:

$$\begin{aligned} x'(\theta) &= \frac{dx}{d(\theta)} = -r(K-1)[sin(\theta) + sin(K-1)\theta] \\ y'(\theta) &= \frac{dy}{d(\theta)} = r(K-1)[cos(\theta) - cos(K-1)\theta] \end{aligned} \tag{5}$$

The stator pitch length, P_s, is defined as a length of a 360 rotation of the crest trace of one helix lobe as shown in Figure3.4. The relationship between the pitch length of the rotor and the pitch length of the stator is given as:

$$P_s = \frac{K}{K-1} P_r \tag{6}$$

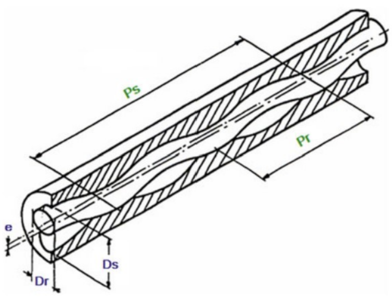

Figure 3.4: Rotor and stator pitch length of 1:2 PCP[15]

Note that K is the number of lobe of the stator. For a single lobe PCP, K = 2 and $P_s = 2P_r$.

The Equation that can be used to plot double helical curve in 3D is:

$$\begin{aligned} x_n &= r((K-1)cos(\theta) + cos((k-1)\theta)) \\ y_n &= r((K-1)sin(\theta) - sin((K-1)\theta)) \\ z_n &= \frac{\theta}{2\pi} P_s \end{aligned} \tag{7}$$

For the 3D modelling of stator in Icesl, these eq7 are used. The eccentricity “e” of a PCP, defined as the difference between the radius of the stator and the radius of the rotor, equals

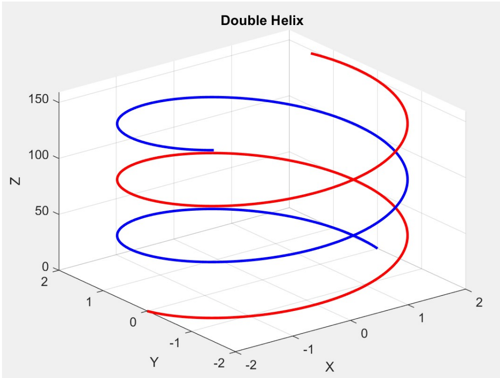

Figure 3.5: Double Helix structure in Matlab

to “r”. In other words, the eccentricity of a PCP is equal to the radius of the generator circle. Consider a K:(K-1) multi-lobe PCP where K is the number of lobe of the stator. This pump is generated by two hypocycloids, namely K lobes and (K-1) lobes. Assuming the diameter of the base circle of the K-lobe hypocycloid is D_{bs} then the diameter of the generator circle is D_{bs}/K[17] Therefore, the eccentricity of this pump, which is the radius of the generator circle, is expressed as follows:

$$e = \frac{D_{bs}}{2K} \tag{8}$$

A PCP will include a K-lobe modified hypocycloid stator and a (K-1) - lobe modified hypocycloid rotor. In addition, there will be (K-1) free spaces between the rotor and the stator, where the fluid flows. Therefore, the flow area of a multi-lobe PCP is $(A_k - A_{k-1})$ and can be calculated using:

$$A_f = A_k - A_{k-1} = 2\pi e^2(K-2) \tag{9}$$

If there is a clearance (a gap), w, between the rotor and stator, the Eq becomes:

$$A_f = 2\pi e^2(K-2) + 4de + 8(K-1)ew + \pi(wd + w^2) \tag{10}$$

The theoretical pump factor, which is the total fluid volume that the pump can discharge as the rotor turns one cycle, which can be expressed as:

$$F_p = (K-1)A_f \times P_s \tag{11}$$

The theoretical pump capacity (idea pump rate when the pump efficiency is 100 percentage) when the rotor turns with a rotational speed of N is given as:

$$Q_{theo} = [2\pi e^2(K-1) + 4de](K-1)P_sN \tag{12}$$

3.3 Rotor construction

The progressive cavity pump rotor is circular in section with each section lying along a helical path . Construction of the geometrical model of the rotor involved defining the position of the helical path in space . Circular sections were then extruded along the path to give the situation shown in figure3.6 The final operation was to turn the skinned volume into what the software recognised as a solid model

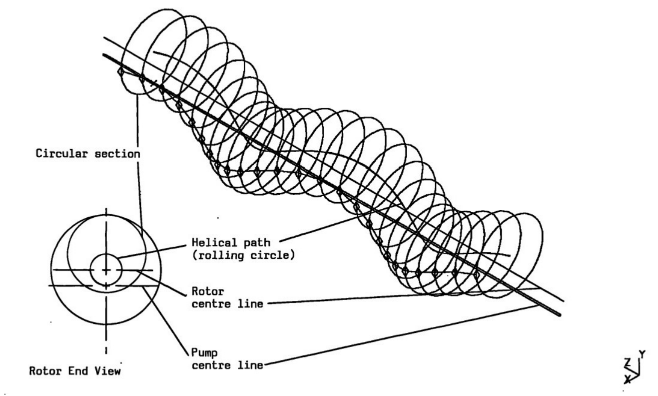

Figure 3.6: Circular sections of helical rotor[3]

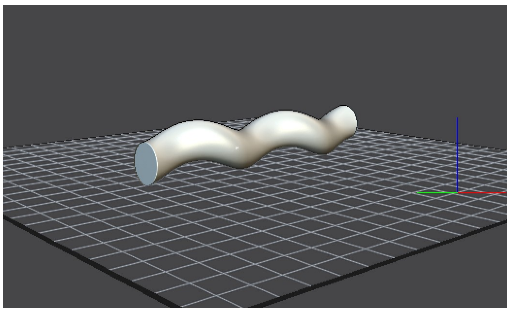

Figure 3.7: Solid model of rotor in Icesl

3.4 Stator construction

The progressive cavity pump stator has an internal form which consists of a slot that turns through 360 degrees along its length. Construction of the stator model involved defining the shape of the stator slot , and rotating it through 360° as it was extruded along the length of the stator. An alternative method of constructing the stator model is to create a profile which consists of the stator slot within an outer diameter[3], This profile can then be rotated through 360° as it is extruded along the length of the stator and can subsequently be turned into a solid model.

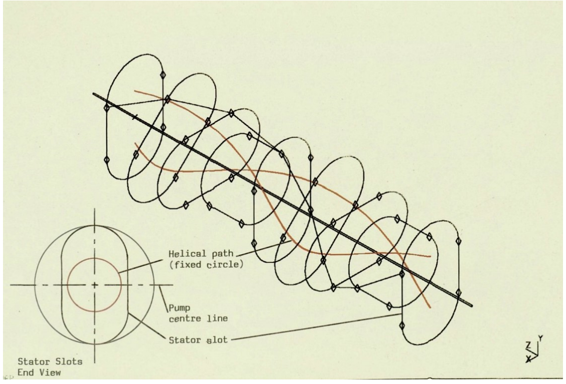

Figure 3.8: Stator Slot Development[3]

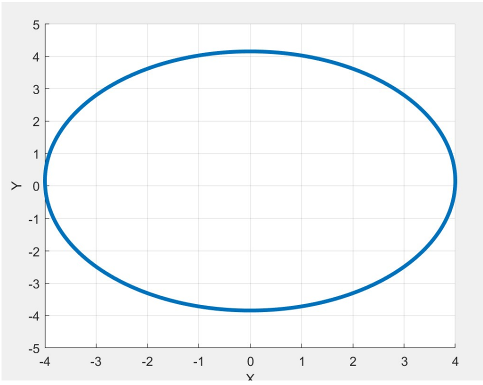

Figure 3.9: Stator Cross section in Matlab

In order to complete the stator model , the core has to be subtracted from another model representing a solid bar. The stator and rotor are modelled seperately in Icesl and put together to obtain the complete pump model.

4 STRENGTH AND WEAKNESS INCLUDING ALTERNATIVE SOLUTIONS

A study conducted by I.R.Belcher [10] explains about the pros and cons of single screw pump.He further explains about the MONO's progressive cavity pump and its competition in the market compared to other pumps. The table represented by this study is shown below:

SINGLE SCREW PUMP	
Advantages	Disadvantages
Self-priming	Gland sealing required
Good suction lift	Cannot run dry
Reversible	Cannot operate at high temperatures
No inlet/outlet valves	Long length to achieve high pressures
Reliable	
Easy to maintain	
Can pump : - abrasives - viscous liquids - solids in suspension - shear sensitive liquids - gaseous liquids	

Table 1: Advantages and Disadvantages of Single Screw Pump

The advantages in the table are explained briefly below:

- One of the main benefits of single screw pumps is their capacity to prime themselves. This indicates that the pump is capable of drawing fluid or material into the pump and creating a vacuum without the requirement for external priming. Single screw pumps are suitable for situations where the pump is situated above the fluid level, such as in a suction lift or in a flooded suction installation because of its self-priming capabilities. In such circumstances, the pump can automatically establish a vacuum by removing air from the suction line, allowing it to pull in fluid or material without the need for manual priming.

- Single screw pumps have the advantage of being able to manage a strong suction lift. The vertical distance that a pump can move fluid or material from a lower level to its input is known as suction lift. The more suction lift there is, the stronger the pump must be to counteract gravity's pull and elevate the fluid or material.

- Single screw pumps have the benefit of being reversible, which allows them to operate in both directions. Accordingly, depending on which way the screw rotates, the same pump can be used to both transport and recover fluids or materials.

- Single screw pumps have the benefit of not requiring inlet or output valves, in contrast to many other types of pumps.There are various benefits to this design. First, it does away with the need for valves, which may be costly, prone to malfunction, and need ongoing maintenance. Second, since there are no impediments in the flow channel, the fluid can flow more smoothly. This can lessen cavitation risk and turbulence.

- Single screw pumps have the benefit of reliability, which makes them a trustworthy and affordable option for many applications.

- Single screw pumps are a practical and economical option for many different applications due to their simple maintenance requirements, which can assist to assure reliable performance and save downtime.

The disadvantages including alternative solutions are explained briefly below:

- The need for gland sealing, which could be a possible site of failure or maintenance issue, is one of the drawbacks of single screw pumps.A technique for preventing fluid leakage along the shaft of the pump is gland sealing [12]. Packing or mechanical seals are commonly used in single screw pumps to accomplish gland sealing. Both kinds of seals need routine upkeep and replacement, which can increase the pump's overall cost and complexity. Due to the drawback of gland sealing being necessary in single screw pumps, more maintenance is needed to ensure the sealing mechanism continues to function properly and prevents fluid leakage. However, single screw pumps can continue to function dependably and efficiently with regular maintenance and the replacement of sealing components.

  One of the solutions for this problem is described by Chuck Tanner[4], which is Compression packing that involves wrapping the shaft with a substance, such as graphite or PTFE, that is pushed against the shaft to establish a seal. It is a conventional technique for gland sealing. Compression packing is reasonably easy and inexpensive to use, although it does require periodic modification to keep the seal.

- The fact that single screw pumps cannot run dry is one of its principal drawbacks. In other words, they need a steady flow of fluid to cool and lubricate the pump parts. The pump may suffer serious damage if it runs dry, necessitating costly repairs or replacement.

  Installing a dry run sensor will help you avoid harm by detecting when the pump is operating without fluid and shutting it off. The majority of pumps may be fitted with little modification using this straightforward and efficient technique.

- Single screw pumps may not be appropriate for applications that call for high temperature operation, which is one of their drawbacks. This is due to the fact that some of the materials used to make single screw pumps, including elastomers, may not be able to sustain high temperatures and may decay or fail in harsh environments.

Use materials that can withstand high temperatures, such as specialized elastomers [10] or high-temperature alloysand Use cooling jackets or external cooling systems to remove heat from the pump and keep it at a safe temperature will help the pump to withstand high temperature

- Single screw pumps may need to be quite long in order to achieve high pressure, which is one of their drawbacks. This is so that pressure and flow can be produced during the pumping action of a single screw pump, which depends on the rotation of a screw within a cylindrical chamber. Higher screw rotational rates are required to reach higher pressures, which may necessitate a longer pump length to allow for adequate fluid compression.

  Without adding length, increasing the screw's pitch can help in creating high pressure. You can achieve this by changing the screw's geometry.Reducing the viscosity of the fluid being pumped can help to achieve higher pressure without requiring additional length. The fluid can be heated to do this, or additives can be used.

5 PROPOSED CONTENT FOR EDUCATIONAL VIDEO

In addition to this report, an educational animated video which will be a part of the study that effectively focuses of the following will be made.

5.1 Design

A clear explanation that primarily focuses on the helical design of stator and rotor.

5.2 Working

The working principle and the factors that would determine different aspects of the pump. eg, pitch of the pump, diameter of the rotor and stator, revolution per minute of the pump, etc

5.3 Desirable features

What makes the screw pump desirable in many situations and to understand if screw pump is the right choice for the situation will be briefly discussed.

6 REFERENCES TO SUPPLEMENT ADVANCED INFORMATION

History and origination of screw pumps have been extensively discussed in the book, Archemedian screw pump by Gerhard nagel [8]. A brief description about the types and applications of screw pump has been posted in the web article [2] by A.A Anderson and Co. In the journal [9], by Jens Gravesen discusses in depth about the Geometry of Moineau pumps. This reference would be helpful for the reader to understand deeply about the stator geometry. The Study of Screw Pump Stator and Rotor Working Capacity to Increase the Output and the wear and tear that occurs have been discussed by K.E. Borisova,T.N, Ivanova,R.G, Latypov[11]. For the reader to know more about the theoretical modelling and design of PCP pumps, the book by Tan Nguyen, Artificial Lift Methods[16] would be helpful.

For the reader to know more about Lua scripting `https://www.lua.org/manual/`. For Icesl documentation, `https://icesl.loria.fr/documentation/` would be helpful.

7 CONCLUSION

In this technical report, we have delved into the geometrical design of single screw pumps, which are a type of positive displacement pump widely used in various industries. We began by discussing the design considerations for the rotor and stator construction of the pump. This included a thorough investigation of the 3D vector theory and hypocycloid theory, which are both essential mathematical models used in the design of single screw pumps.

Designing a single screw pump in Lua script can be a challenging yet rewarding task. However, with proper knowledge of the Lua programming language and an understanding of the principles behind single screw pump design, it is possible to create a highly optimized and functional pump design. This report would be helpful for readers to model Single screw pump in Icesl with help of Lua script.

We have highlighted the strengths and weaknesses of single screw pumps, as well as alternative solutions that can be employed in certain applications. To facilitate learning and understanding, we will propose an educational video that focuses on the design, working, and desirable features of single screw pumps. We believe that this video will be a valuable resource for engineers, students, and anyone else interested in the field of fluid dynamics and pumping systems.

The report contributes to the understanding of the design and operation of single screw pumps and provides valuable insights for anyone who is interested in Screw pumps.

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