

# New Type of Reversible, Invertible, Variable Hydraulic Pump/Motor

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## ABSTRACT

This paper is devoted to a new type of fluid power pump/motor. Architecture of the proposed pump/motor is considered. Thanks to its advanced kinematics many advantages are achieved so these advantages are described in this paper as well as some bench tests results and possible applications.

## INTRODUCTION

In this paper a new type of hydraulic pump/motor will be introduced. This new device is not similar to devices that are commercially available currently. It is a breakthrough in pump architecture, which can lead to incredible performances and benefits.

At the beginning of the paper the main principle of this pump will be considered, the core part of the paper will be a familiarization of the technical advantages and test results and some examples of applications will be given in the conclusion.

## MAIN PRINCIPLES OF THE DEVICE ARCHITECTURE

The presented pump is not similar to conventional pumps. Although it corresponds to known types of hydraulic pumps/motors, we are not able to compare its architecture with known types, so it will be described from scratch.

The architecture will be presented with increasing complexity shown in the diagrams. See Figure 1 and imagine the barrel of a revolver. There are some openings along the barrel axis into which sliding vanes are inserted. The shape of these sliding vanes does not matter in general but according to our investigations the most appropriate shape is cylindrical. The sliding vanes are able to reciprocate in the openings.

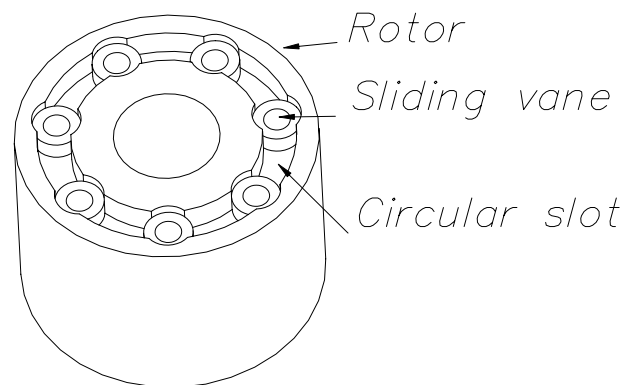


Figure 1. The rotor with the sliding vanes.

One end of the rotor comprises a circular slot; the other end is flat. The slot is slightly narrower than the openings so an additional surface for the sliding vanes position is provided. The slot is one of the main parts of the working chamber. Two partitions are the other boundaries of the working chamber. Figure 2 illustrates how the partitions are mounted.

The partitions are positioned in the circular slot so that they can separate the high-pressure area and the low-pressure area. One of the partitions, the "regulating partition", does not touch the bottom of the circular slot, but touches the upper ends of the sliding vanes. The other partition the "separating partition" touches the bottom of the circular slot.

The sliding vanes move forward into the working chamber while the rotor is rotating. Then they slide along the regulating partition and then slide back into the rotor. While the sliding vanes are moving along the regulating partition a displacement of fluid is created.

## Separating partition

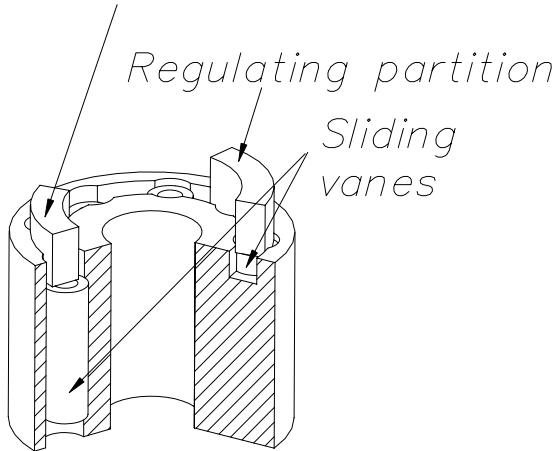


Figure 2. The regulating and the separating partitions.

There are many ways to make sliding vanes to reciprocate. In this particular example one of several options is shown. The sliding vanes are equipped with projections as shown in Figure 3. The sliding vanes are driven by these projections.

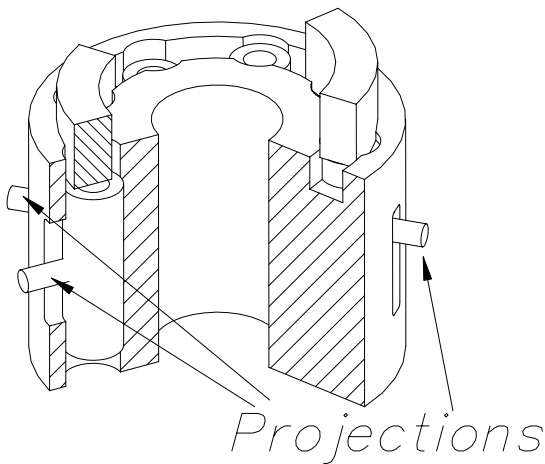


Figure 3. The projections.

As usual, the rotor is placed within the housing and rotates against it. A special guide is mounted in the housing and does not rotate. See Figure 4. The guide is a sinusoidal shaped slot. The guide directs the sliding vanes to reciprocate in the openings along the rotor axis,

while the rotor is in motion. The projections can be equipped with rollers or any kind of bearings but this will be illustrated with simple projections without bearings. These projections move along the guide slot and the sliding vanes are driven towards the working chamber and back.

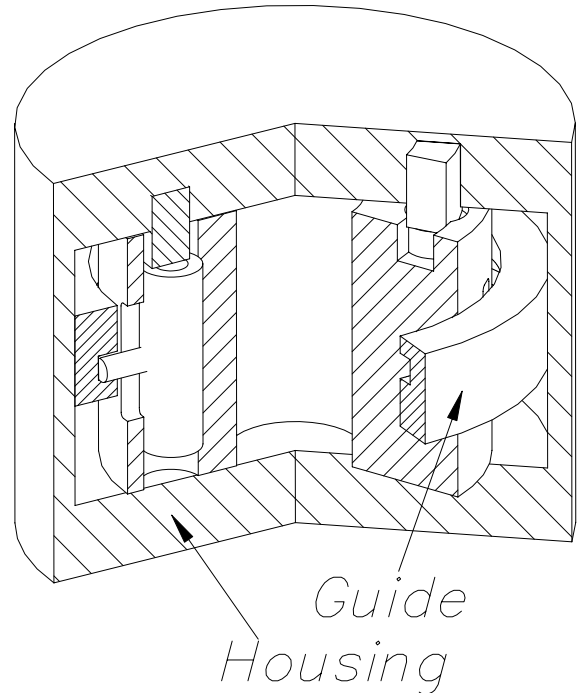


Figure 4. The guide and the overall mounting.

A cylindrical projection of the rotor and the circular slot are shown at Figure 5. The rotation operates from left to right. The fluid is received from the suction area, then they slide along the regulation partition and pump the fluid into the pumping area. The sinusoidal guide is not seen in the diagrams. It is very important to note that the sliding vanes displace fluid by their side surfaces, not by their ends. Their action is similar to those of vanes in a vane pump.

As has already been said, while the sliding vanes are implementing the displacement, they are fixed not only by the rotor's openings but also by the cavities arranged in the circular slot. While the displacement is being provided there is no movement of the displacers, e.g. the sliding vanes are immovable. This prominent feature makes this device similar to vane pumps, but the rigidly fixed sliding vanes allow many incredible performances, unattainable in conventional vane pumps.

Another important feature of the proposed device are the channels that connect the opposite ends of the rotor. As is seen in Figures 1 and 5 openings are provided in the

sliding vanes in order to enable the equalization pressure in opposite ends of the rotor. The second end of the rotor is flat and it slides along a special part fixed in the housing. We called this part the distributing element.

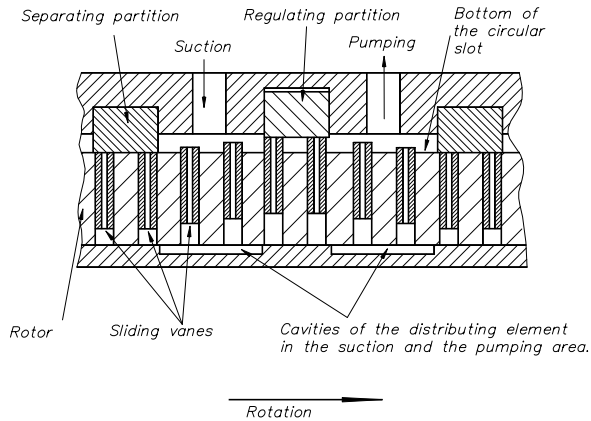


Figure 5. The radial section view of the rotor and the circular slot.

In this particular example the distributing element is shown as a part of the housing for better understanding, but in real devices it should be independent of it. In this element there are two kidney shaped cavities located opposite the high-pressure (pumping) and low-pressure (suction) areas of the working chamber. These kidney shaped cavities are shown in Figures 5 and 6.

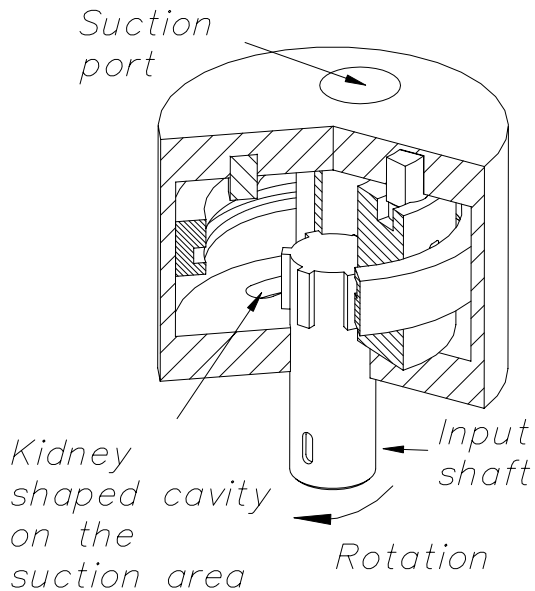


Figure 6. The kidney shaped cavity.

These cavities connect the neighboring sliding vanes so that the second end of the rotor is divided into two areas: high-pressure and low-pressure, which have surface areas equal to those in the working chamber. Each cavity connects sliding vanes that are under equal pressure. The cavity on the suction area is shown in Figure 6. The cavity corresponding to the pumping area is not shown there. Thanks to these cavities and channels in the sliding vanes the rotor is operated under equal axial forces acting from both of its ends. Any pressure is possible in the working chamber, but the rotor will be balanced anyway.

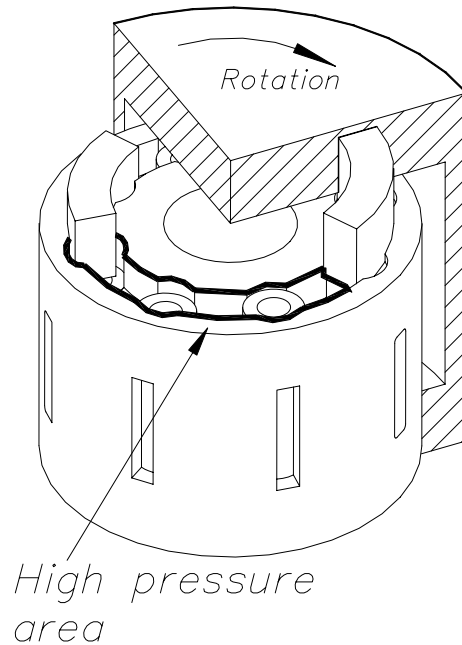


Figure 7. The high pressure area.

We also would like to attract attention to the balance of the rotor in radial direction. It is shown in Figure 7. The high-pressure area is limited by the circular slot, the separating partition from one side, the sliding vanes from another and the housing from the top. The resultant radial force acting on the rotor will be absent.

Considering the entire architecture of this pump/motor we would like to outline next important features:

- The displacers (sliding vanes) are rigidly fixed into the rotor.
- The displacers are balanced along the axis due to the openings made in them.
- The rotor is also balanced along the axis due to the openings in the sliding vanes and the cavities in the distributing element.

- The rotor is balanced in the radial direction.

The device described has fixed displacement, but it is very easy to vary the displacement. For that the guide would be moved simultaneously and the regulating partition. If the regulating partition moves closer to the bottom of the circular slot, the sliding vanes will protrude less from the rotor. A smaller part of the sliding vanes will perform the displacement. The transition volumes between the two neighboring vanes will decrease, so the displacement will decline. If the regulating partition moves further from the bottom of the circular slot, the working volume will increase and the displacement will increase respectively.

It is possible to use any kind of rod to control the guide and the regulating partition simultaneously. These rods can be connected to any drives which can be located at any side of the housing. Usually they use hydraulic power to drive the control mechanism due to big forces occurring in the mechanism of conventional pumps. The prominent feature of the proposed device is that it is not necessary to use any power drives. All parts and nodes of the pump are balanced, so there is just a dynamic resistance to regulating force. It leads to a simple and light regulating mechanism and low response time.

### TECHNICAL ADVANTAGES AND APPLICATIONS.

Previously the architecture of the proposed pump/motor was considered. Some experimental units have been produced and some bench tests of these units were carried out. Technical details have been changing from unit to unit, but the main principles of its architecture have been kept. In spite of some differences in details, the pump being made in any version showed the common features:

- Low noise level;
- Smooth output flow;
- Resistance to back impulses of pressure, e.g. "hydro hammer".

Some units had some specific features such as extremely compact design, but the features mentioned were observed in several versions.

Consider these advantages more attentively.

### NOISE

We measured the noise level of an experimental unit with a working chamber of 25 cm<sup>3</sup>, the tested version of the pump was variable. The noise level was measured in a non-anechoic room. Bench tests were carrying out in a normal room without any special sound dampening preparations. Although we registered a noise level of 64 dBA, while pressure was 200 bar, rotation speed was

2500 RPM and displacement was full. Usually a noise level measured in an anechoic chamber is lower by 2-4 dBA. Our investigation shows that the noise level will be the same at higher pressure, up to 300 bar.

### SMOOTH OUTPUT FLOW

The most important feature of the pump/motor is absolutely smooth volumetric displacement. Consider Figure 5 and 8 to illustrate that. While a sliding vane is performing suction, the axial movement of the vane occurs. Thanks to the channel in the vane the volume of fluid, which is displaced by the volume of the vane itself, flows to the area below the vane. When the vane moves back to the rotor, the volume of fluid below the vane flows back to the pumping area. The cavities of the distribution element connect the openings in the rotor that are at the moment under the same pressure (high or low). Thus, axial movements of the sliding vanes and their own volumes do not influence the overall volumetric displacement. Both zones 1 and 2 are involved in the transition of the fluid: the closed volume between two neighboring vanes and volume in the openings below the sliding vanes. These two transition zones compensate each other, and with additional help of the cavities in the distributing element the pump has absolutely smooth volumetric displacement.

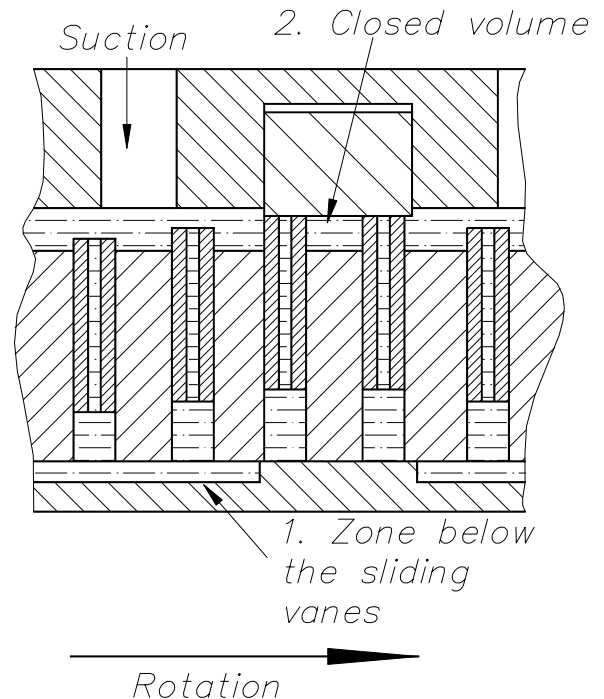


Figure 8. The compensation of the volume of the sliding vanes.

## RESISTANCE TO BACK IMPULSES OF PRESSURE

Resistance to “hydro hammer” becomes more and more important in two main aspects: water hydraulic and special applications. Consider these two topics.

Water hydraulic is very interesting area of hydraulics development in general due to some essential features. Two of them are that the water hydraulic is clean and fireproof.

Special applications such as mine tools are widely used. It is strictly prohibited to work in a mine with oil as a working fluid in hydraulic tools because of the fire risk. A special water mixture is used there as a working fluid in all hydraulic tools and equipment. Axial-piston pumps/motors as well as vane pumps/motors work successfully with this water mixture, but they are not resistant to back impulses of pressure, which occur, for example, when a chisel hammer is used as a load. Gear pumps/motors are resistant to this kind of impulses but they cannot work with the water mixture.

The proposed pump/motor is able to work with the water mixture as a working fluid and is extremely resistant to back impulses. This is clear from the architecture of the pump/motor. While displacement is being provided, the sliding vanes under pressure are hard fixed in the rotor by means of openings and semicircular cavities that are seen in the Figure 1. The sliding vanes under pressure do not reciprocate with respect to the rotor. The force of pressure is not transferred to the sinusoidal guide or to any other parts and nodes of the pump, which can be damaged by pressure, so impulses of pressure act on the hard fixed sliding vanes, the rotor and bearings of the shaft and the rotor. Obviously, these parts are extremely resistant to impulses of pressure. Anyway, it is easy to make them durable enough.

## APPLICATIONS

Industrial and mobile applications of this pump are at least as numerous as those of axial piston pumps. The proposed pump has similar properties such as maximal and working pressure, maximal rotation speed, working fluid etc. The overall range up to 5000 rev/min is covered by the proposed pump as well as the range of maximal pressure up to 420 bar. The proposed pump is able to work with special water mixtures without any problems as the pump’s architecture allows this.

The market of axial piston pumps is rather wide. For example annual shipments of closed loop variable axial piston pumps in 1997, according to the US Census Bureau, amounted to 1.188.663 units at a value of 314 million dollars. This figure has not changed a lot since 1997. We suggest that any application where an axial piston pump/motor is used may be redesigned with the proposed pump. The benefits are obvious.

- Hydraulic systems in general will be much more quiet.

- Applications will become wider thanks to pressure impact resistance.

Some applications are not so obvious but they are as important as the whole aerospace industry is. One aerospace application of the proposed pump is the fuel-feeding pump. It is necessary to feed turbines and any another fuel combustors smoothly. Designers use different devices in order to eliminate pressure pulsations in fuel pipes. These fuel feeders cost a few tens of thousand dollars and have considerable weight which is vitally important for the aerospace industry. This situation resulted from some additional devices used with the aim of decreasing pressure pulsations. The proposed pump is not needed for any additional devices, so a lower weight and cost can be achieved.

## VARIATIONS OF ARCHITECTURE

In the current paper only one type of architecture was considered from many different possible ones. There are many types to suit different special purposes.

One of them is an architecture with two circular slots at opposite ends of the rotor and two sets of partitions. Each end of the rotor includes a circular slot with partitions and each end works as an independent pump. When the displacements of those two parts of the entire pump are equal the overall displacement is zero. The machine displaces a fluid from one part to another without any positive overall displacement. When the displacement of one part is zero the overall displacement is maximal. When the opposite part of the machine has zero displacement the reverse occurs. A simplified plan of this kind of configuration is shown in Figure 9.

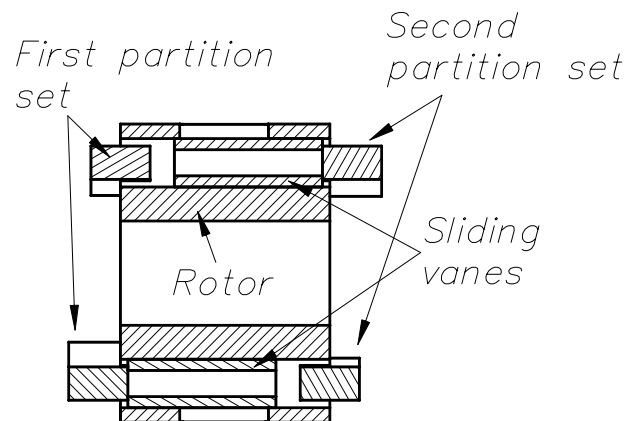


Figure 9. The reversible pump/motor.

Another type of architecture has two or more working chambers placed on one end of the rotor. By means of this multi-chambered rotor a high-torque hydro motor

can be developed. The overall torque of this kind of motor will be multiplied in a number of chambers.

The mechanism of the pump regulation may be placed within the rotor. This mounting allows the creation of a compact and light design.

Bearings can be also mounted on the outside of the rotor as well as the inside, so depending on different applications and purposes the pump can suit them completely.

The proposed pump has a simple structure, which does not require any special equipment for its production. It is allowed to use the usual equipment, which is installed in plants. So the expenditure for the development of commercially available devices will not be higher than those for the new axial piston pump or a new vane pump.

## **CONCLUSION.**

The described pump discovers new opportunities for hydraulic system in general. A combination of a quiet operation and the high pressure range expand the application field of these devices and increases its competitiveness in face of new noise emission requirements.

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