Alternating Flow Hydraulic Generator for Water Jet Cutting Systems

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Abstract: *The paper describes new approaches regarding the water jet machining systems. There are presented some aspects of the design possibilities of the water jet cutting head in the context in which the main hydraulic power supply is not a conventional one, but one who can provide directly an alternating flow, considering also the involved disadvantages of this solution.*
The second part present a some concepts regarding the design of an alternating flow hydraulic generator, and details regarding the functioning conditions which can increase the reliability of the alternating flow generator and also of the entire system.

Keywords*: alternating flow, hydraulic generator, water jet cutting*

1. General aspects

The water jet cutting technology was patented in 1968 by Dr. Norman Franz under the name "jet cutting technology at high pressure" from the McCartney-Ingersoll Rand, U.S.A.
After three years, in 1971, the water jet cutting process was implemented on the first industrial facility, and in that way the Flow Systems Company from U.S.A. became its main promoter in the industrial sector and the world leader in this technology. [3], [4]
The first steps in industrial applications have been made in the aviation industry, where the jet cutting technology was used for processing materials such as plastic, multilayer materials, composite, and others.
In 1984, the Flow Systems Company produces the first water jet cutting-abrasive installation. This innovation constitutes a genuine revolution in jet cutting technology, giving it a whole new dimension. The technique enables cutting of most materials, metallic or non-metallic, special alloys, composites and ceramics. This versatility gives it a good position compared to other recent cutting technologies (ex. plasma, laser). [3], [4]
In general, the abrasive water jet cutting processes are used for cutting operations, but there are some other applications for operations like turning, milling, or deep drilling.
The main parts of any water jet cutting machine are: the hydraulic pump, which provides pressured oil, an amplifier, in which the pressure of water is increased and the cutting head, where the water is mixed with abrasive from the system, if the processing conditions require that.
Like [4] presents, after the experimental researches with a sonic wave generator, as primary source of hydraulic energy, the conclusions were: transmitting energy in the form of pressure waves from sonic generator to cutting head allows mounting the cutting head amplifier into the cutting head, which offers the advantages of water transport pipeline working pressure metal or Kevlar and also, that the amplifier has very low reliability. Improving the system performances require an increasing of the operating pressure and reliability. For this purpose, the proposed changes are: the increasing of the pressure wave amplitude provided by the sonic generator and the increasing of the amplification ratio in the cutting head.
The sonic wave generator, previously mentioned, is an alternating flow generator which can provide, during the functioning of the system, a pressure and a volumetric flow in each connection pipe, which varies in a harmonic way, around an average value.
Generally, an alternating flow driven hydraulic transmission consists in an alternating flows and pressures generator and a motor, the connection between them being realized with a number of pipes, equal with the number of phases. The pipes must be first being filled with hydraulic oil at a pre-established pressure, obtaining in this way the correct functionality of the entire alternating flow hydraulic system. This pressure is modifying itself, naturally, during the functioning. [5]

2. Approaches on the water jet cutting head design

Water jet machines can manufacture parts to very good tolerances. Today, the modern water jet cutting machines can create parts with a tolerance as small as 0.05 mm, although it is usually easier to obtain tolerances under 0.1 mm. [3], [4]
The productivity and costs of processing are other important factors which determine the parameters of the abrasive jet processing and sometimes they may be even critical in choosing this process.
In [2] is described a water jet machining system comprises a alternating flow generator with the role of transforming mechanical energy produced by the electrical motor in pressure waves, that are transmitted through a hydraulic fluid to the amplifier mounted in the cutting head. The amplifier consists of two pistons with different diameters.
The disadvantage of this solution is the difficulty of obtaining a reliable piston seals that act directly on the water at high pressure.
Also, another problem is the reliability of the alternating flow generator, due to high pressure and low displacement. To eliminate these disadvantages, was proposed a solution using an amplifier with membranes, which can increase the amplification ratio and avoid water penetration in sealing area.
In figure 1 and in figure 2 is presented the architecture of a cutting head with amplifier for alternating flow.

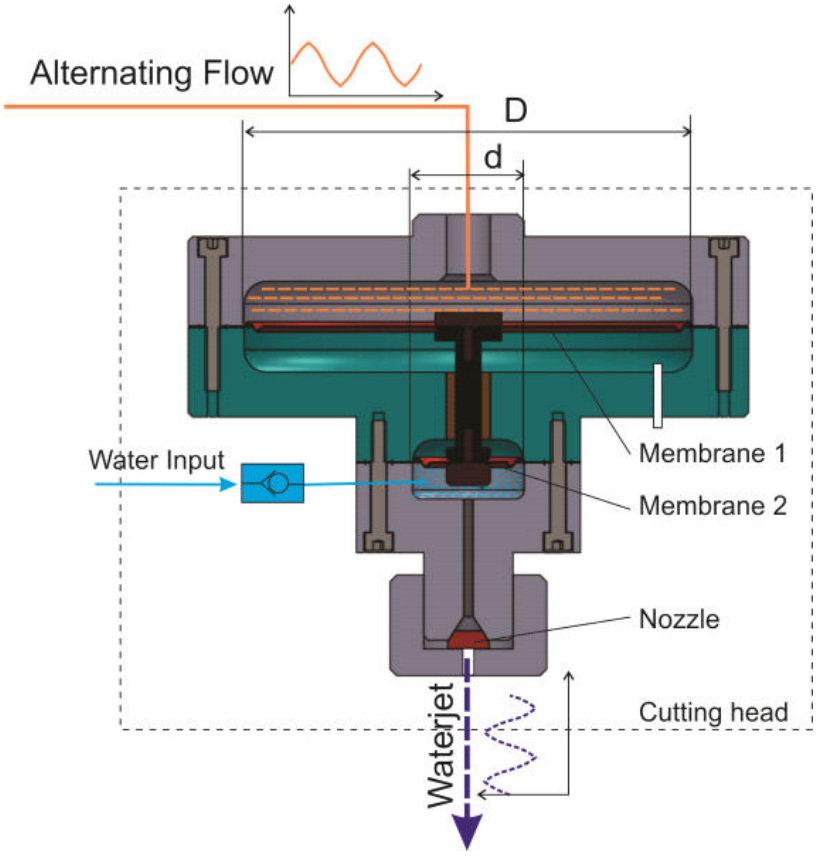

Fig. 1. Water jet cutting head without check valve and dumper

The pressure waves from alternating flow generator acts to the large membrane 1 that move up-down together the small membrane 2 and increase the water pressure due amplifier ratio. A continuous jet is obtained using a check valve and a dumper after amplifier, figure 2.
Also, to increase the performances and the lifetime of the alternating flow generator, this one can be designed with two functional opposite phases. But, in this way, between the cutting head amplifier and the generator we must include other specific components which provide a single exit

way for the main hydraulic power supply, using for this purpose some hydraulic pressure transformers and one way directional valves. These are not represented in the principle schema.

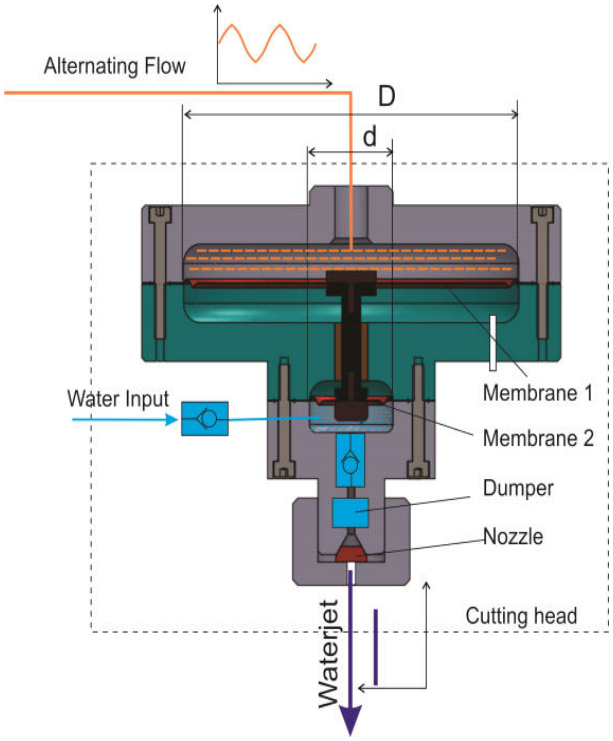

Fig. 2. Water jet cutting head with check valve and dumper

A cutting head with amplifier for pulsed jet that permit to obtain the amplifier ration over 20:1 is shown in figure 3.

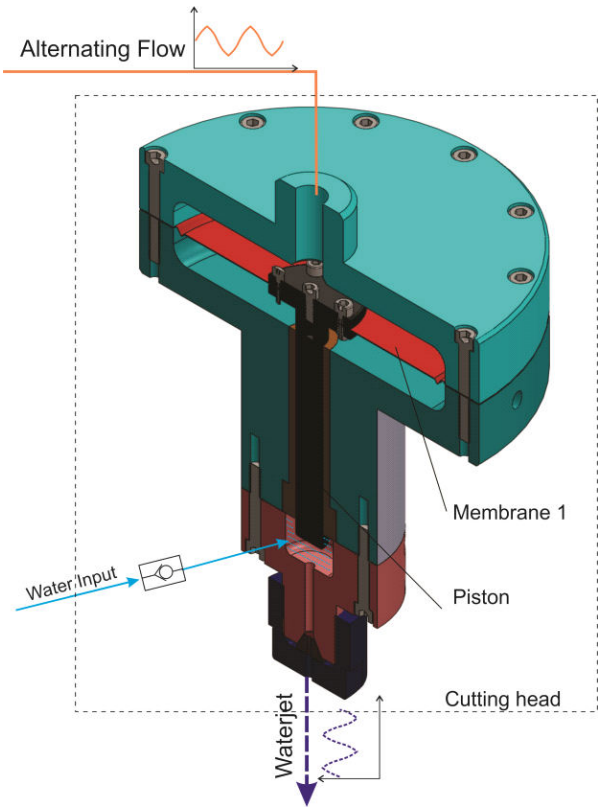

Fig. 3. Water jet cutting head for pulsed jet

3. Approaches on the alternating flow generator design

A hydraulic transmission using alternating flows involves a bidirectional displacement of a finite volume of hydraulic oil through the connection lines between a hydraulic generator and at least one small hydraulic linear motor. [5]
If the system is working in two phases, then the equations that governing the volumetric flow (instantaneously flow) for the each phase, according to [5] are:

$$Q_{i1} = Q_{a\max 1} \cdot \sin(\omega t + \varphi_0) \tag{1}$$

and

$$Q_{i2} = Q_{a\max 2} \cdot \sin(\omega t + \varphi_0 + \pi) \tag{2}$$

in which

$$Q_{a\max} = \omega \cdot r \cdot S \tag{3}$$

is the amplitude of alternating flow for the each phase.
Figure 4 presents the principle design of a biphasic alternating flow hydraulic generator with two opposite radial pistons.

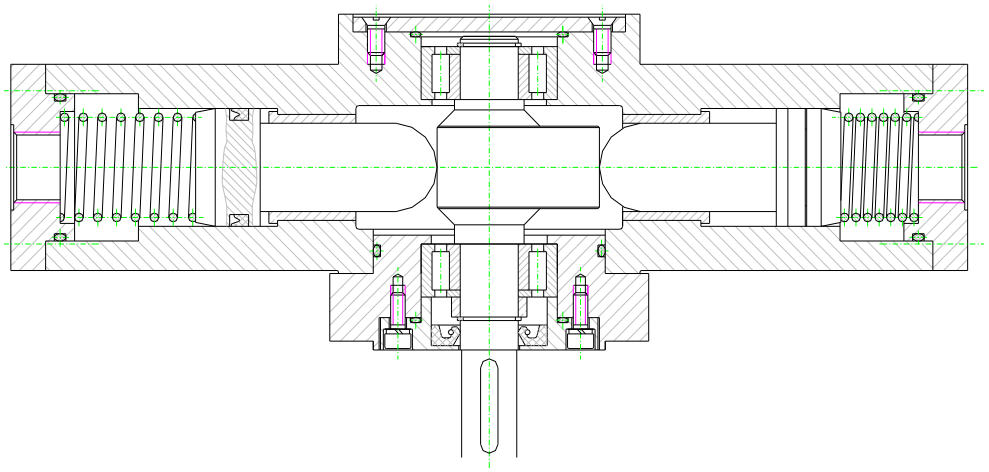

Fig. 4. The principle design of the biphasic alternating flow hydraulic generator

Figure 5 present the evolution of the piston volume and volumetric flow for the each phase of the alternating flow generator, based on equations (1) or (2) and (3), and also considering the established dimensions of the main components.

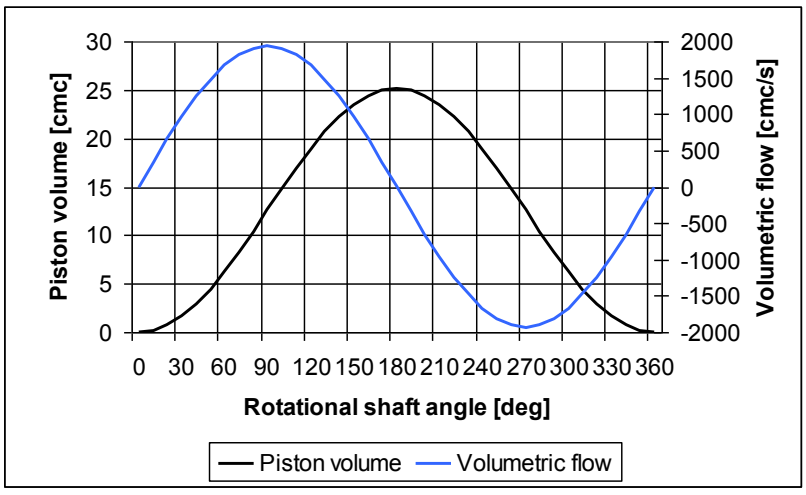

Fig. 5. Theoretical evolution of the piston volume and volumetric flow of the generator

The main shaft of the generator, presented in figure 4, can be realized using sinusoidal cam profile, preventing in this way the pressure shocks. According to the constructive parameters of the alternating flow generator and the sinusoidal cam law, the obtained stroke of the pistons is presented in figure 6.

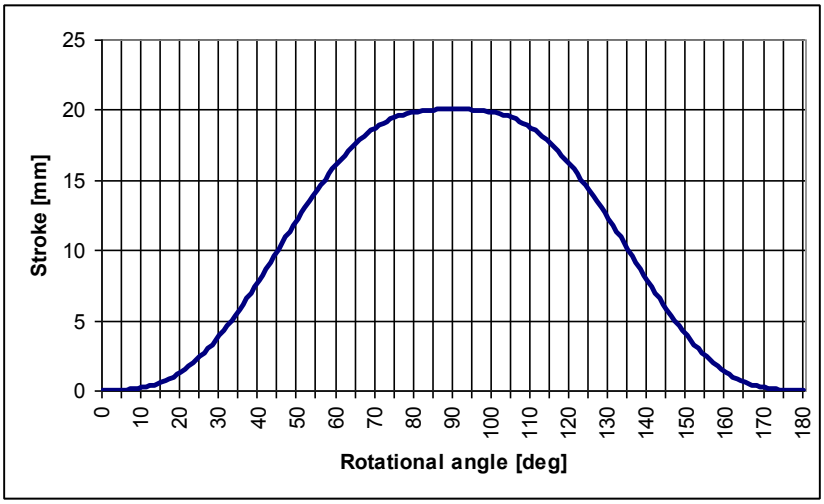

Fig. 6. Theoretical evolution of the alternating generator piston stroke

In figure 7 is present the principle schema of the biphasic alternating flow hydraulic system which provides the alternating flow for the membrane amplifier of the water jet cutting heat.

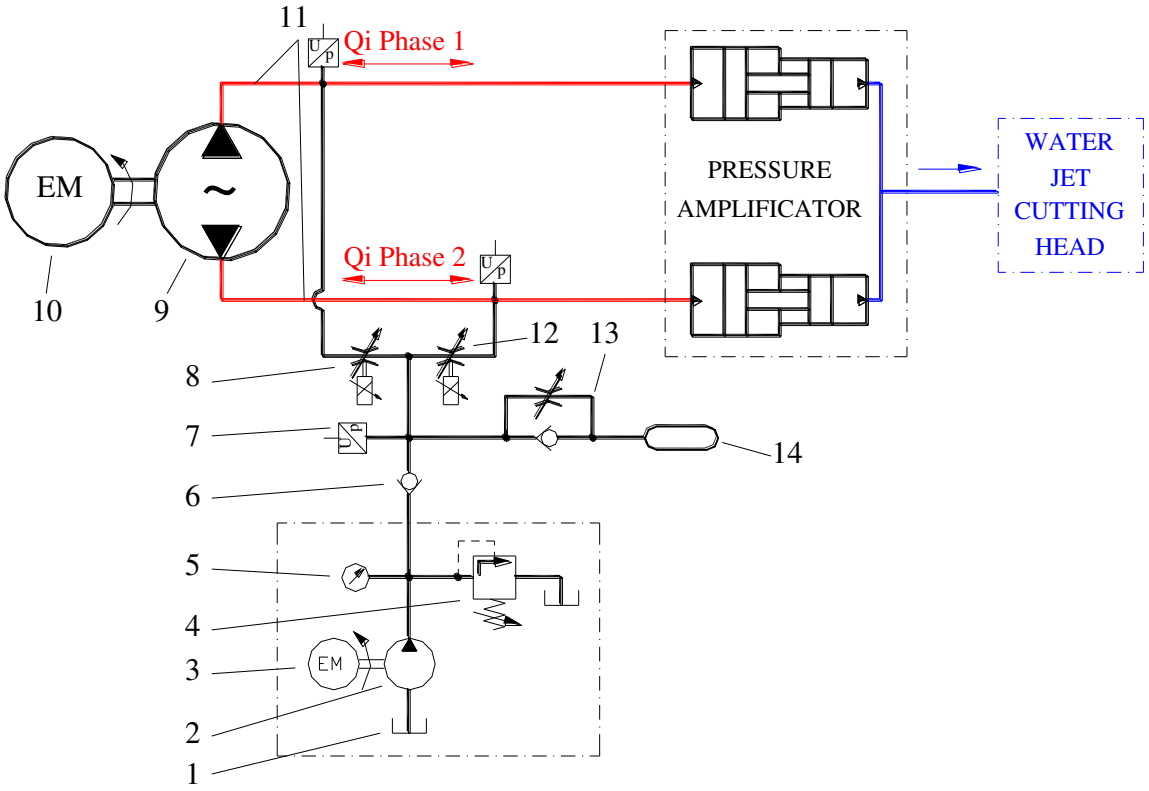

Fig. 7. The principle schema of the biphasic alternating flow hydraulic system

During the functioning of the alternating flow system, the pressure and the flow within each pipe varies in a sinusoidal way, around an average value, and not continuously like in the classical

hydraulic systems. These can be easily controlled with a monitoring system, deigned like in [1] and [6] is presented.
As figure 7 shows, the alternating flow generator is functioning in a closed circuit. Due to that fact the accumulator 14 presence is compulsory, and it makes the pressures in the connection lines to be all the time approximately constant. Also, the hydraulic accumulator is able to take over the oil surplus from the dilatations and in the same time to complete any external oil loses (in drains).
Between the phase lines must be placed some hydraulic resistances, proportional controlled in this case. These can eliminate the maximum average pressure rising value in one second when the diminution of the flow amplitude from a phase does not exceeds 1%, according with the researches presented in [7].
The medium oil pressure value in the accumulator is provided by using an auxiliary hydraulic system which includes a small volumetric hydraulic pump 2.

4. Conclusions

The paper describes the constructive principles of an innovative water jet cutting head. The membrane amplifier offers the possibility to obtain a very compact design, with low inertial forces.
The uses of the alternating flow generator, together with an adequate pressure transformer, provide for the cutting head amplifier the right form input signal.
All of these, combined with sensor and computer application especially developed, can to collect and control in an optimal manner functional parameters of the entire system.

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