# DESIGN AND TESTING PRINCIPLES OF THE ALTERNATING FLOW DRIVEN ROTARY HYDRAULIC MOTORS

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**Abstract.** The paper presents some aspects regarding the design and testing of an alternating flow driven, three-phase rotary hydraulic motor. The hydraulic transmissions using alternating flows are based, on the bidirectional displacement of a finite (predefined) fluid volume through the connection pipes between the alternating flow and pressure energy converters (generator and motor). In principle, within these systems, the active stroke of the pistons, is produced by the pressurized fluid flow from the generator, while, for the return stroke there is necessary a supplementary connection to a pressure generator, working in opposite phase with respect to the first one. The pistons can be connected either in a star or delta configuration.
**Key words:** Alternating flow, rotary hydraulic motor, star/delta connection.

**Rezumat.** Lucrarea prezintă aspecte privitoare la construcția și testarea motoarelor hidraulice rotative, trifazice, cu debite alternante. Sistemele hidraulice cu debite alternante se bazează pe o curgere bidirecțională a uleiului sub presiune între convertorii de energie. În principiu, aceste tipuri de motoare pot fi configurate în stea sau în triunghi.
**Key words: ???????????????????????????**

## 1. GENERAL ASPECTS

All known methods of power transmission by fluid, and their applications, are based on continues pressure, and flow circulation, which are achieved by the pump, and collecting by final elements, we considered fluid is uncompressible.

In conventional hydraulic transmissions, the fluid performs a unidirectional motion between the energy converters in the power transmitting process. In alternating flow driven hydraulic transmissions, the fluid executes an alternative periodical motion between the energy converters.

If is considered a hydraulic system in which every working volume of an alternating motor is connected independently, by a phase pipe, with the corresponding working volume of an generator, then any modification of the volume of the generator will produce an alternative flow and pressure transmitted along the phase line to the motor.

In principle a very simple version of an alternate hydraulic transmission consist in two interconnected hydraulic cylinders, presented in figure 1.

The periodical movement is transmitted to the piston of the first cylinder by a crankshaft mechanism, the piston executing a bidirectional movement, which provides an alternative flow *Q*, and consequently a bidirectional flow between the two cylinders chamber. Consequently the second cylinder will move synchronous with the first.

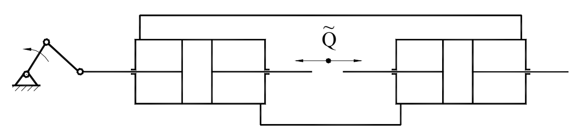


**Fig. 1.** Working principle of the alternating flow driven hydraulic transmission. [3]

We assume that the governing equations for the instantaneous flow and pressure are: [1, 3]

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

and for the pressure:

$$p_i = p_{st} + p_{a\max} \cdot \sin(\omega t + \varphi_0) \tag{2}$$

in which: $Q_i$ is the instantaneous flow; $Q_{a\max}$ – alternating flow amplitude; $p_i$ – instantaneous pressure; $p_{a\max}$ – static pressure; $p_{a\max}$ - alternating pressure amplitude; $\omega$ - angular frequency; $t$ - time; $\varphi_0$ - initial phase angle;

As the figure 1 presents, an alternative hydraulic transmission is a closed circuit and it not requires a tank for the working fluid. In other words we have hydraulic oil only in the pipes whose connect the energy converters (generator and motor).

For every forward movement of the generator piston an alternative flow will be generated, as well a high pressure zone will be formed. The final effect is a longitudinal oscillation of the fluid mass, which moves along the fluid line, starting from the generator piston side to the motor piston.

If in the system pipes the initial pressure is zero, then the movement of the generator piston will provide only positive pressure peaks.

By taking account the compressibility of hydraulic oil, it is possible that the motor piston to not move synchronous with the generator piston or worst, to not move at all, depending on the lines (pipes) length, figure 2. To avoid this situation the system will be external pressurized to an initial static value $p_{st}$ , (see equation 2 and figure 3), which provide a symmetric evolution of the instantaneous pressure in the system pipes.

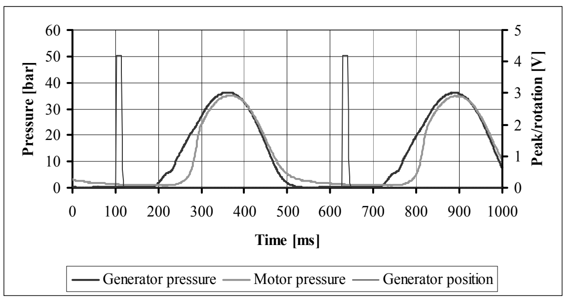


**Fig. 2.** Asymmetric evolution of the instantaneous pressure.

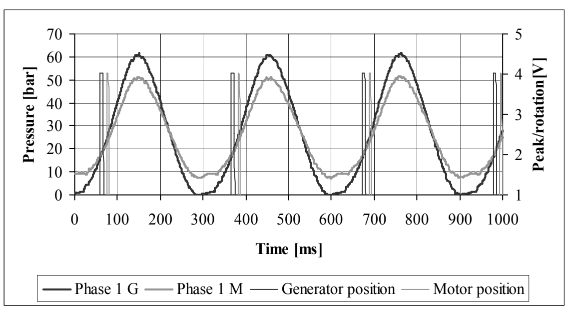


**Fig. 3.** Pressure diagram at a speed of 3.3 rot/s, static pressure 20 bar.

The pressure amplitude in each phase is dependent of flow amplitude needed by the motor as of other factors like: the liquid elasticity from a phase, the liquid inertia from that phase, the hydraulic loses between motor and generator, the motor load.

## 2. THE DESIGN OF THE ALTERNATING FLOW DRIVEN HYDRAULIC MOTORS

The construction of rotary hydraulic motor working with alternating flows, tested on an experimental stand, allows two types of interconnection configurations between the phase pipes and motor working volumes (cylinder chambers), which are in star or in delta, each of them with their individual particularities.

In principle, the designed rotary hydraulic motor consist in three associated hydraulic double end cylinders, with small dimensions, which act individually to an output shaft, obtaining in this way a continuous rotational movement of this.

In figure 4 is presented schematically the star interconnection configuration of the working volumes of the motor cylinders.

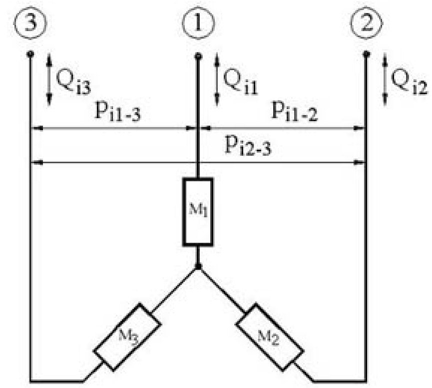


**Fig. 4.** Principle of the star interconnection of the motor working volumes. [1]

Figure 4 shows that each phase pipe (line) is connected individually to a working volume of the motor cylinders, providing in this way the active stroke of the pistons. The working volumes (chambers) of the cylinders are interconnected. In this way, if we taking account that the movement of each piston have a difference of the phase on 120°, the advance of one motor piston will generate a same flow in the star connection, which provide the retraction stroke (idling stroke) of the next two pistons.

A characteristic of the star connection is that the sum of alternating flows in the connection point is theoretically zero.

The delta interconnection configuration is presented schematically in figure 5.

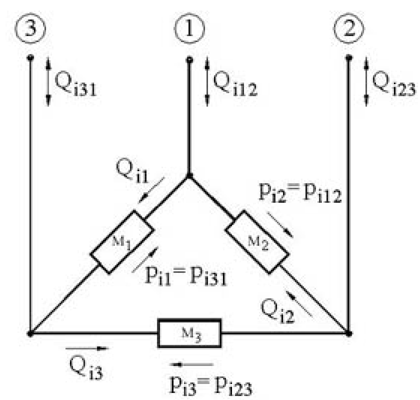


**Fig. 5.** Principle of the delta interconnection of the motor working volumes. [1]

The delta connection involve that each first working volume of an cylinder, which is providing the active stroke, is connected with the second working volume of the next phase cylinder, providing in this way his retraction stroke (idling stroke), the pressures in this chambers being, of course theoretically, at the same values.

The hydraulic motor was designed in two versions. The compact model, figure 6, having gear rack conversion mechanisms associated to each small hydraulic cylinder group.

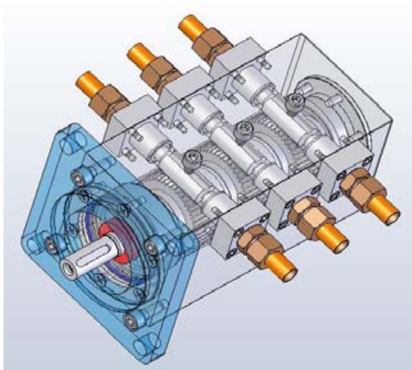

**Fig. 6.** Alternating flow driven hydraulic motor with gear rack conversion mechanism.

Figure 7 presents in detail the gear rack conversion mechanism, of the piston strokes, which collect the movements from the oscillatory oil column.

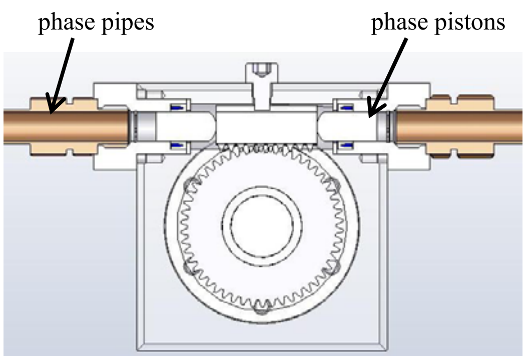


**Fig. 7.** Detail - motor gear rack conversion mechanism.

In figure 8 is presented an experimental model of the alternating flow driven rotary hydraulic motor with pulley and elastic steel sheet conversion mechanism.

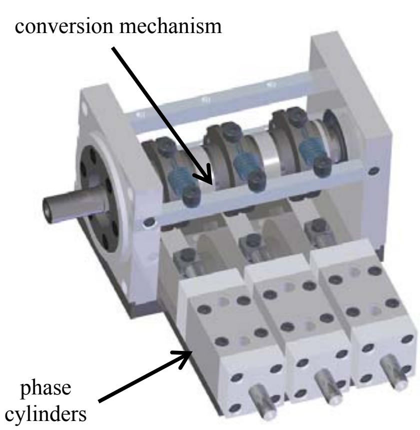


**Fig. 8.** Alternating flow driven hydraulic motor with pulley and elastic steel sheet conversion mechanism.

Each designed versions of the alternating flow driven rotary hydraulic motor contains three double end hydraulic cylinders which act individually some pulleys (or gear), having mounted inside drawn cup roller clutches and in this way the rotational motion and also the torque is transmitted unidirectional to the output shaft of the motor.

## 3. THE TESTING PROTOCOL OF THE ALTERNATING FLOW DRIVEN ROTARY HYDRAULIC MOTORS

Testing that kind of hydraulic motor involve a precisely control of the mechanic and hydraulic parameters, and so collecting as experimental data is possible. To do so, the second version of the hydraulic motor, figure 7, was preferred, and also in the system was mounted some proximity sensors, pressure sensors and displacement sensors.

Because the functioning of the experimental model was tested in idling condition and also loaded, the output shaft was coupled to a braking device, acted by a small hydraulic cylinder, which allows loading on the shaft torques at different values.

In order to measure as many functional parameters as possible, the experimental stand was designed in such a way to be easy reconfigured. Therefore, the experimental stand has not a compact configuration.

A series of functional parameters of the alternative flow driven hydraulic system was obtained directly, figure 9, as: [2]

- Angular speed of the shafts, generator and motor;
- Pressures:
  – on the generator;
  – on the motor, idle and loaded;
  – in the phase line pipes;
  – in the interconnection pipes;
- Motor pistons strokes.

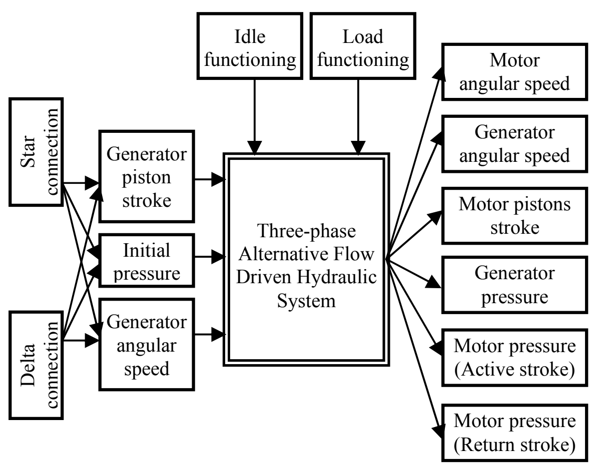


**Fig. 9.** The input/output parameters diagram.

Some of the diagrams were obtained indirectly, using the recorded data referring to:

- Transmitted torques;

• Phase alteration between:
– alternative flow and harmonic pressure;
– rotational position of the generator and motor shafts.

The preliminary experimental data, figure 10 and figure 11, representing the functional parameters, were obtained considering the monitoring protocol, figure 9, was reviewed and processed afterwards, taking into consideration each particularly mechanical configuration and input adjustments. The pressures and the motor piston strokes evolution during the increase of the generator angular speed, was directly provided by the sensors, for both, the star and delta interconnection configurations, in idle state, and also on load state.

On load functioning is realized using a hydraulic braking device. This way the output shaft of the motor is loaded at different values. Figure 12 present, for example, "on load" diagram with different measured parameters, and by varying the initial conditions, rotational speed and piston strokes of the generator and the loaded static pressure is obtained a complete image on the limits "in loaded" conditions of the designed motor and so for the system.

The experimental data collected and also the processed data provides a complete image on the limits of the designed hydraulic motor and so far for the entire system functioning with alternative flows.

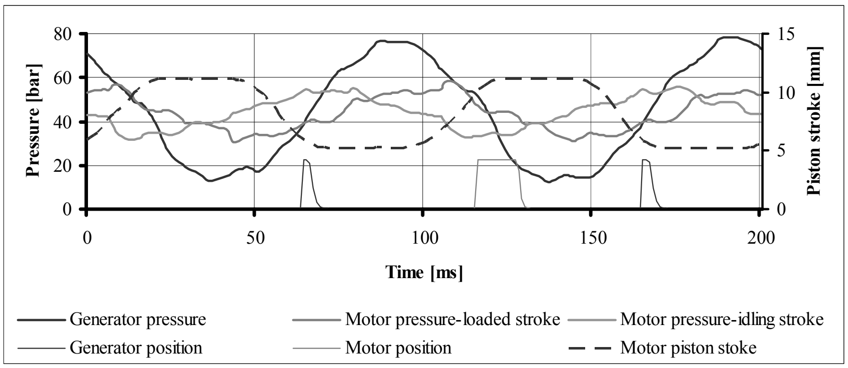


**Fig. 10.** Pressures, motor piston stroke, rotational speeds diagram, for delta interconnection configuration at: static pressure 40 bar, generator piston stroke 10 mm and rotational speed 10 rot/s.

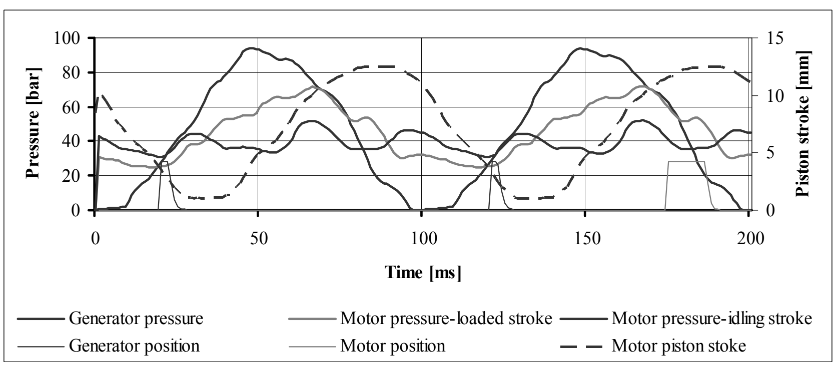


**Fig. 11.** Pressures, motor piston stroke, rotational speeds diagram for star interconnection configuration at: static pressure 40 bar, generator piston stroke 12 mm and rotational speed 10 rot/s.

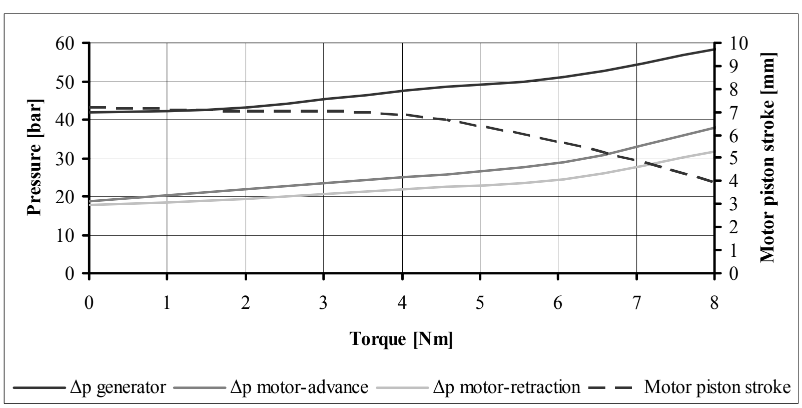


**Fig. 12.** Evolutions of pressures, motor piston stroke - torque, for delta interconnection configuration at: static pressure 25 bar, generator piston stroke 10 mm and rotational speed 5 rot/s, in load state.

## 4. CONCLUSION

The objective of this research was a new approach of the hydraulic drives, in which the pressure and flow is not continuously transmitted between the energy converters.

Within these systems, the active stroke of the pistons, is produced by the pressurized fluid flow from the generator, while, for the retraction stroke there is necessary a supplementary connection to a pressure generator, working in opposite phase with respect to the first one, which means that the pistons can be inter-connected in a star or delta configuration.

## 5. REFERENCES

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