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Original Research Article

The basics of design and experimental tests of the commutation unit of a hydraulic satellite motor

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ABSTRACT

The article presents an analytical method to design the commutation unit in a hydraulic satellite motor. It is shown that the size of the holes feeding the working chambers and their location on the plates closing those chambers depends on the geometrical dimensions of the working mechanism. The overlap in the commutation unit depends on the rotational speed range. It is demonstrated that the geometrical dimensions of the commutation unit clearances change as a function of the angle of machine shaft rotation. The flow in these clearances is described as $Q = f(\Delta p^{\gamma})$. It has been observed that during the transition from the cycle of filling to the cycle of emptying the working chamber, the pressure in the motor's working chamber changes linearly as a function of the shaft rotation angle which has a significant effect on leakage in the commutation unit clearances. The methodology of investigating the commutation unit in a satellite motor and the mathematical model of leakage in the commutation unit clearance described in the article may be successfully adopted to research the commutation unit in positive displacement machines of another type.

1. Introduction

Each hydraulic positive displacement machine consist of the following units:

a) the working mechanism with working chambers which change their volume when the machine shaft is revolving;
b) a commutation unit, the task of which is to ensure the appropriate process of filling and emptying the chamber of the working mechanism;
c) a unit of internal channels supplying liquid to the commutation unit.

The geometry and kinematics of the working mechanism elements and the process of filling the chambers of this mechanism determines the design solution of the commutation unit node. A hydraulic positive displacement machine of any type should have an original type of the commutation unit node designed specifically this machine. For example:

a) in axial piston displacement machines the commutation unit is composed of a cylinder drum and a directional valve disk [19] or a cylinder sleeve coupled with the cam on the shaft performing a reciprocating motion and cyclically switching the working chamber with the supply or outflow channel [6];
b) in gerotor machines the working mechanism chambers are supplied by: the shaft, a special disk revolving together with the shaft [10,20] or the commutation unit is made of gear wheels and feeding holes in the casing [3,9,9].

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List of symbols

d_f root diameter of satellite teeth [mm];
h_s the clearance height [μm];
k the coefficient of overlap of inflow/outflow holes in the commutation unit [–];
m the teeth module [mm];
n the rotational speed of the motor shaft [rpm];
n_R, n_C the number of stator, rotor humps;
Δp the pressure drop in the motor [MPa];
Δp_i the pressure drop in the working chambers of the motor [MPa];
C, C_1, C_2, C_t constants;
D_e the diameter of the inflow and outflow hole in the commutation unit plate [mm];
D_o the diameter of the inflow and outflow hole in the commutation unit plate for the zero overlap [mm];
J the geometrical overlap [mm];
L the clearance length [mm];
Re the Reynolds number [–];
Q_t the theoretical displacement of the motor [l/min];
Q_{Cm} the liquid flow rate in commutation unit clearances [l/min];
Q_C the volumetric loss caused by the flow of liquid in commutation unit clearances [l/min];
V_g geometric working volume of the motor [dm^3/rev];
V_t theoretical working volume of the motor [dm^3/rev];
α the shaft rotation angle [deg];
α_b the shaft rotation angle at which the flow Q_{Cm} disappears/is formed in the commutation unit clearance [deg];
γ the coefficient depending on the flow type;
ν kinematic viscosity of liquid [mm^2/s];
ρ liquid density [kg/m^3].

Such an original solution of design of the working mechanism and the commutation unit node is also characteristic of the satellite motor [1,12–14]. The design and principle of operation of this motor are presented in the next section.

The design solution and the precision of making the commutation unit in each positive displacement machine has a significant impact on:

a) the smoothness of the rotational speed;
b) the smoothness of the torque;
c) the volumetric loss.

Therefore, the design of the commutation unit node for a satellite motor is an important scientific and technical issue. Therefore, four main goals are set for this work:

a) develop a method to design the commutation unit node in a satellite motor;
b) build a motor with a commutation unit made in accordance with the adopted method;
c) perform experimental tests of the motor in order to:
   - verify the commutation unit design methods;
   - confirm the correctness of the flow processes in the commutation unit node;
   - investigate leakage in the commutation unit node;
d) perform a detailed analysis of leakage in the commutation unit and provide a mathematical description of them.

2. Satellite motor

The satellite motor design is presented in Fig. 1. The working mechanism of the satellite motor is a specific gear mechanism in which the rotor is revolving around the shaft axis and the revolving motion is generated by satellites which are coupled with the stator and the rotor (Fig. 2).

The stator teeth are inside and it has six humps ($n_C = 6$). The rotor teeth are outside and it has four humps ($n_R = 4$). The gear wheels called satellites work with the stator and the rotor. Spaces called working chambers are formed between the satellites, the stator and the rotor. The number of the working chambers is equal to the number of the satellites.

During the rotor rotation the working chambers:

a) change their volume from minimum $V_{k\text{-}min}$ to maximum $V_{k\text{-}max}$ forming a high pressure chamber HPC;
b) change their volume from maximum $V_{k\text{-}max}$ to minimum $V_{k\text{-}min}$ forming a low pressure chamber LPC.

The number of filling and emptying cycles of the working chambers per one rotation of the shaft, z_c, is:

$$z_c = n_C \cdot n_R \tag{1}$$

The shaft rotation angle α_{DC} in respect of which the change from $V_{k\text{-}min}$ do $V_{k\text{-}max}$ takes place, is:

$$\alpha_{DC} = \pi \cdot \frac{z_k}{z_c} [\mathrm{rad}] \tag{2}$$

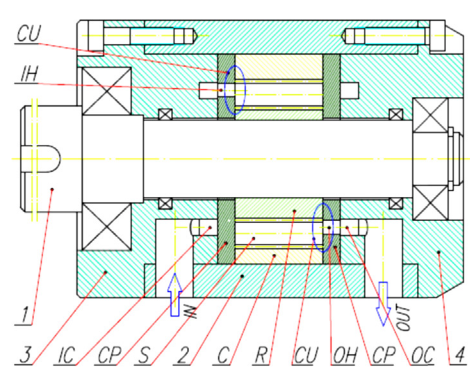

Fig. 1 – Satellite motor design: 1 – shaft, 2,3,4 – casing elements, C – stator, R – rotor, S – satellite, CP – commutation plate with holes of liquid inflow IH to and outflow OH from the working chambers, IC and OC – inlet and outlet manifold, CU – commutation unit.