6

THEORETICAL AND EXPERIMENTAL INVESTIGATION OF LEAKAGE FLOW IN GEAR PUMPS

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ABSTRACT

The leakage losses in gear pumps, represent a special interest in engineering service. Herein, the prediction of leakage flow, as related to the pump geometry and fluid properties, has been assumed. Theoretical analysis has been developed to estimate the leakage flow through the side and radial clearances, during meshing process, and by squeezing of the trapped fluid. Theoretical and experimental analysis showed a satisfactory agreement between the estimated and the measured values.

Introduction

Gear pumps, as positive displacement pumps, are of special importance in hydraulic service due to their simple construction, design and relatively low prices. In spite of these advantages, the high leakage ability limits these pumps for low pressure use. The excessive increase of the internal clearances deteriorates the pump performance. To estimate the clearances allowances during the pump service, a theoritical and experimental study have been developed . Detail analysis of the leakage sources enable the user to estimate the limits of pump service life based on the clearances allowances that affect the pump performance.

Theoretical Investigation

Fluid leaks, for spur gear pumps, from the high pressure side to the suction one through; [1 ,3]

- radial clearances, between the pump gears and casing,
- side clearances, between the gears sides and casing,
- backlash losses, during the meshing process,
- sqeezed fluid, at the end of meshing process.

a) Radial clearance leakage

To estimate the radial clearance leakage between the pump gears and casing, one dimensional steady laminar developped flow, has been assumed. The pressure drop per tooth is mainly due to local losses at both entrance and exit of the radial clearance p_l, and friction losses between the pump casing and teeth crest p_f. The friction losses pressure drop may be estimated by assuming one dimesional laminar flow between two parallel plates,

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6

with moving boundary at linear velocity u, Fig. 1, [2 , 4]

$$p_f = 12 \; z \mu (v - u/2) / e_r^2 \quad , \tag{1}$$

where z is the number of teeth per gear, μ is the fluid dynamic viscosity, v is leakage mean velocity, and e_r is radial clearnce.

The local losses pressure drop, between the pump inlet and outlet, may be assumed as,

$$p_l = z (k_i + k_e) \rho v^2/2 \quad , \tag{2}$$

where k_i and k_e are the local loss coeffecient at inlet and exit of the tooth, and ρ is the fluid mass density.

In this case the pressure difference between the pump inlet and exit p_p is the sum of pressure drops across the teeth,

$$p_p = p_f + p_l \quad , \tag{3}$$

The leakage flow velocity v may be calculated from equation (3). For two gears pump, the radial leakage flow may be written as.

$$q_r = 2 \; z \; e_r \; (v - u/2) \; b \quad , \tag{4}$$

where b is the gear width.

Equation (4) may be written in dimensionless form as, [1],

$$(p_p/\rho u^2/2)) = 2 \; z \left(\frac{v}{u} - 1/2 \right) \left(\frac{\mu}{\rho e_r u} \right) \left(\frac{b}{e_r} \right) + + (k_i + k_e) \left(\frac{v}{u} \right)^2 \tag{5}$$

b) Side clearnce leakage

The side leakage losses take place btween both the teeth, and gears sides, q_{s1} and q_{s2} successively. The side leakage loss q_{s1} can be calculated by using equation (1), in nagl-ecting the tangential velocity term (u/2). The upper and lower parts of the gears are moving in opposite dirctions. The leakage q_{s2} may be assumed to be proportional to the teeth lose,as , 8 ,

$$q_{s2} = K \; q_{s1} \quad , \tag{6}$$

where K is assumed to be,

$$K = H / R_r \tag{7}$$

with H is tooth height , and R_r is the root radius of the gear.

The leakage flow velocity v_s may be calculated from equation (1), in neglecting the term (u/2). The side leakage loss q_s may be written as,

$$q_s = 2 \; (1 + K) \; v_s \; H \; e_s \; , \tag{8}$$

where e_s the side clearance.

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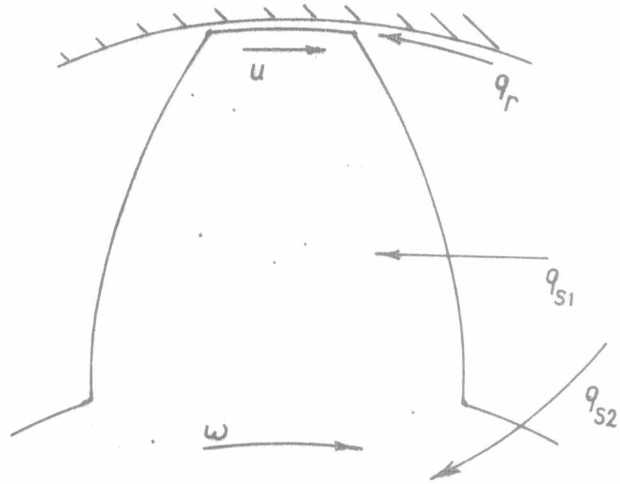

Fig.1. Radial and Side leakages

c) Backlash leakage losses

During the teeth meshing process, a part of the fluid leaks from the high pressure side to the low pressure one through the contact area of meshed teeth. This part of losses may be assumed to be dependant on the fluid vicosity, pressure, as well as the teeth geometry, life and surface finish, 2 .

The backlash loss may be written as,

$$q_B = K_B \, z \, n \, p_p \quad , \tag{9}$$

where q_B is the backlash loss, n is the pump speed rps, and K_B is a coeff-ectient, has to be estimated experimentally. For now pumps this part of losses is of megligeable value.

d) Squeezed Fluid

As the gear rotates, it is observed that, during an incremental time, a small quantity of fluid is completely trapped by the meshed teeth. Further rotation of the gears, results in squeezing the trapped fluid. This part of sqeezed fluid has been estimated experimentally, by measuring the change of enclosed volume between the meshed teeth, as a function of the gear angular rotation. A gear plastic model has been used to estimate this variation of trapped volume, [1] . The squeesed part q_{sq} may be taken to be,

$$q_{sq} = 0.002 \text{ to } 0.005 \text{ of the theor tical discharge} \quad (10)$$

The theoritical pump discharge can be calculated as ,

$$Q_t = V_g \, n \quad , \quad (11)$$

where V_g is the pump geometric volume, which is the discharged volume per revolution, and n is the pump speed per second.

e) Total leakage losses

The total leakage losses may be calculated as the sum of the losses in different parts of the pump. From equations 4,8,9,10 the total losses q is,

$$q = q_r + q_s + q_B + q_{sq} \quad (12)$$

Experimental Investigation

To verify the proposed leakage equations, derived in the theoretical part, an experimental study has been carried out for a spur gear pump having the following dimensions,

Gear external diameter D_{ex}	$= 0.035$	m,
Gear width b	$= 0.02$	m,
Tooth height H	$= 0.0055$	m,
Tooth mean width b_t	$= 0\ 0025$	m,
Number of teeth z	$= 12$	
Geometric volume V_g	$= 9.52 \times 10^{-6}$	m^3/ rev
Radial clearance e_r	$= 0.75 \times 10^{-6}$	m
Side clearance e_s	$= 0.1 \times 10^{-3}$	
Oil viscosity	$= 0.0176$	N.s/ m^2
Pump speed n	= 1200 and 1500 rmp	

The pump has two gears mounted in the casing between dplates, to reduce the side clearance as the outlet pressure increases. Due to the difficulties of estimating the side clearances as a function of the pumping pressure, the pressure compensating action on the side plates has been blocked. The maximum value of side clearances has been taken into consideration, that results in higher values of both measured and calculated side leakages.

The pump internal leakage has been evaluated by measuring the actual pump flow rates for different speeds and loading pressures. The leakage was calculated as the difference between the measured and the theoritical flow rates, (Eq. 11).

The measuring test stand is given in Fig.2. The driving motor speed is controlled by means of a servo system which allowed to have a constant pump speed, independent of the pumping pressures. The outlet pressure oscillation, due to flow pulsation, has been damped out by means of fitting a hydraulic accumelator in the measuring circuit. The flow rates have been measured by a calibrated orifice. For small values of flow rates the volume measuring method has been used. Experimental results are given in Fig.3. On the same figures, the theoretical calculated reslts are given, also, that show satisfactory agreement.

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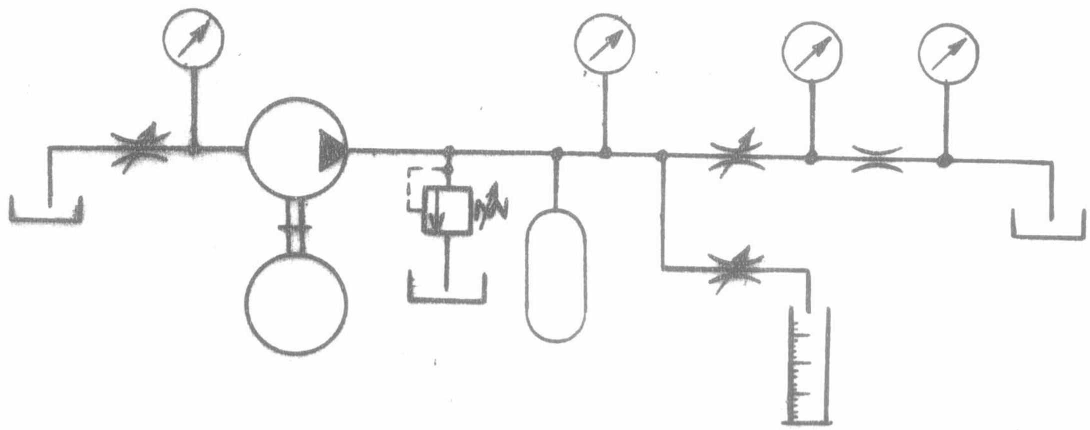

Fig.2. Experimental Test Stand.

Conclusions

The leakage losses in gear pumps are due to the radial clearance, side clearance, teeth backlash, and fluid squeezing at and of meshing process. The proposed method of estimating these sources of leakage losses, has shown that the radial and side clearances are only important to evaluate the pump volumetric losses. Theoretical and experimental analysis show a satisfactory agreement, between the estimated and measured values. It is of economical interest to estimate the pump performance and service life on theoritical base by measuring the pump clearances.

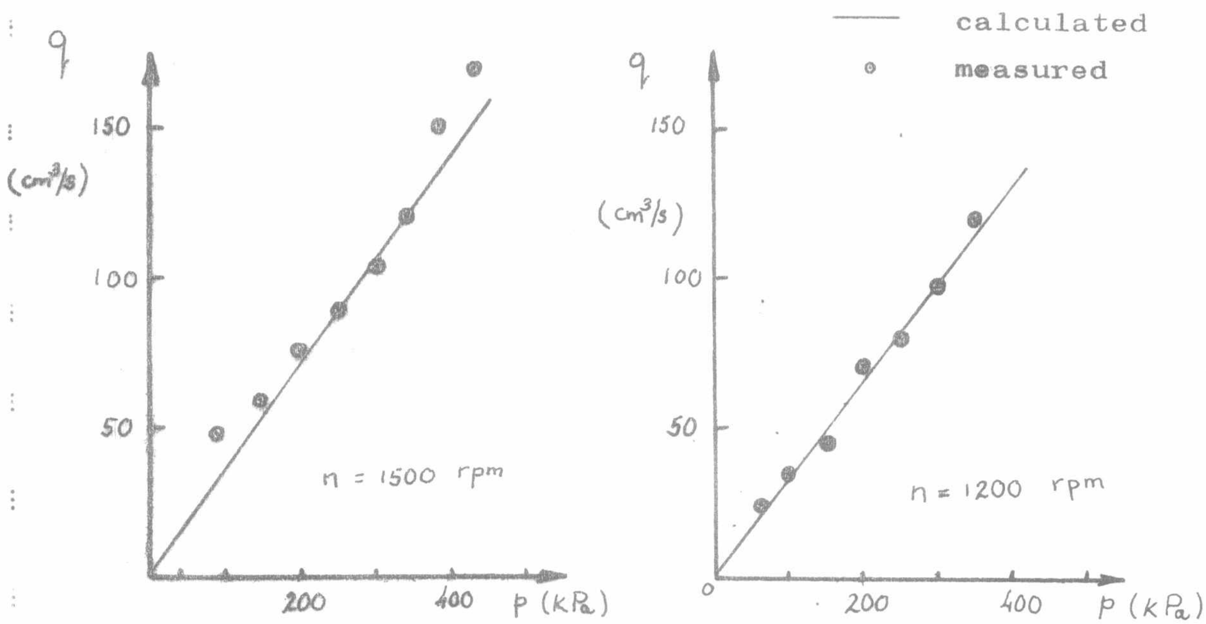

Fig.3. Experimental and Calculated Leakages

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