Original Paper

Numerical Analysis of Standard - Unstandard Gears for an External Gear Pumps

Ahmed Mustaffa Saleem¹, Bahjat Hassan Alyas¹ and Zaid Ali Shaalan¹

¹Northern Technical University, Mosul, Iraq
Mosul, 4100, Iraq, ahmedmustafa@ntu.edu.iq, bahjatalhayaly@gmail.com, eng_zaid_al@yahoo.com

Abstract

The most widely of hydraulic applications power employed source that including low manufacturing costs and good performance are defined as the external gear pumps. In this study, the using of unstandard gears and influence on the performance of gear pumps are studied. These influences include pulsation factor of flow rate, flow rate of pump and trapped volume between two meshing gears. Matlab software has been used to evaluate performance by modifying algorithm and deriving the equations of pump flow rate. The unstandard gear is used in the study undertaken with +0.3 Rack shift coefficient. Results indicated the using of unstandard gears increase flow rate and reduce the trapped volume and pulsation flow rate factor. It was concluded that the factor of pulsation flow rate reduces as increase of teeth number which leads to pulsation flow rate stabilization.

Keywords: unstandard Gear pump; pulsation flow rate; Pump performance.

1. Introduction

The gear pumps are among the most commonly and oldest used in the industrial applications. The large applications of unstandard gear has led to be the main choice for fuel system designers due to high reliability, minimum maintenance, long life, small size, capability to operate with low lubricating fuel, low heat in-put to fuel and low weight.

In order to generate flow a simple mechanism (two gears) has been used in the external gear pumps therefore, it has a minimum number of parts associated with the design. However, there are number of factors ignored with the design, as the pressure peaks and the volumetric efficiency can greatly affect the pump performance. Liping el al. [1] were introduced a new approach of modeling the hybrid exterior equipment pumps experimentally. Details of the exterior tools pump parameters have been provided. They were conducted predictions set for some results of the post processing to be validated with the other experimental data.

Egbe [2] was designed and analyzed, fabrication and trying out of an exterior gear pump was once efficiently carried out. Indicated an exact prospect for the fabrication and design of small system machines which will serve as a spring board for development and technological switch.

The aspects of this tools pump have been fabricated through machining. Rana [3] was studied with the assist of exterior helical gear kind equipment pump check rig generate experimental statistics with the used of contaminated burnt oil as fluid medium. Setup was running at a specific rpm with adjusted velocity of motor thru vari-o-state, which measured with the assist of the tachometer. The overall performance of exterior gear pump has been checked at an exclusive rpm of equipment rotor. These statistics validated with the theoretical estimation and there is found appropriate agreement.

Yoshida [4] was developed a new theoretical evaluation of the leakage via the clearance between gear tips with eccentricity and the housing, and the pressure state which is distributed alongside the gear circumference. This new theoretical evaluation used to be beneficial in the prediction of the optimization flow rate performance and its dispersion in accordance to the tolerance of the dimensions, as properly as the prediction of bearing load which is very essential inside the format stage of rotary machine.

Wang et al. [5] were observed the relationship between the flow pulsation and the gear sorts of pumps, inclusive of staggered gear pumps, helical gear pumps and straight gear pumps. However, research that contain experiments and simulations to affirm the principle have been few. Based on the principle of staggered gear pumps, the paper analyzed the pump flow characteristics of various unique gear teeth types, respectively, with the aid of making use of the software program Pump linx which is effective in fluid analysis.

Li et al. [6] was studied the components of displacement calculation of the pump theoretically which was used to be derived from quantity alternative method, and the pulse traits can be got with the aid of evaluating the maximum instant displacement and minimal displacement.

It was obtained the equation of tooth profile of the double round arc helical gear, the gear conjugation principle and the transition...
line as the sine curve.

It was presented a theoretical foundation for the look up and improvement of the double-arc helical gear pump.

Tian [7] was designed of comfort chamber related to the region of trapped to absorb the pulses pressure cycle which has been used to be tested and the trapped projected location extent has been solved the use of a two dimensional method of morphological. Lumped parameter pressure dynamic model has been used to be derived, approaches and the simulation conditions have been illustrated. The overall of the proposed algorithm performance and the relief chamber outcomes have been discussed and evaluated.

Mali et al. [8] were studied the behaviour numerical research on the exterior gear pump casing, taking into account the whole three-dimensional geometry and go with the flow instability. It has been finished the usage of the commercial software program package deal CFX. The gear pump was once made of two or greater gears that rotate internal a closed casing. The movement of the pressure gear used to be generated by using the motor, and the action of the pushed gears was once generated by way of the meshing of the teeth of the two gears. When the gears started out to rotate, the teeth come into contact with every other and designed. When the teeth depart away the contact area, a vacuum was once generated.

Avram et al. [9] were studied theoretically and experimentally static and dynamic performances of a pump. Theoretical evaluation implies to increase a mathematical model of the pump operation and the first step of its constructing was once to describe the theoretical pumping capacity. They were introduced four different methods for pumping capability calculation for external gear pumps, with numerical statistics applied, in order to compare the results. It was observed that this technique was improved the pump mode.

The present paper was investigated the using of unstandard gears and their influence on the gear pumps performance. These influences included pulsation factor of flow rate, pump flow rate and trapped volume between two gears meshing.

2. Physical model

i. Pump Description

The system is contained two gears, one of them is defined the driving gear which connected to the shaft and the other one is defined the driven gear which is free. The meshing has been conducted for two gears individually. It was created two chambers by the gears coupling with bushing blocks sliding for each one of gears. Figure 1 indicates the housing of pump which connecting two plates with the gears.

![Fig. 1 Schematic diagram of main external gear pump [11].](image)

ii. Description of Model

The theoretical part of this study includes the complete tooth shape mathematical model involutedly gears which can be derived the tooth profiles equations form. The unstandard and standard specifications of external gear pump selected for this study are illustrated in Tables 1 and 2.

| Table 1 | Specifications of standard gear pump. |
Table 2 Specifications of unstandard gear pump.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rack shift coefficient</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Number of teeth</td>
<td>8 - 10 - 12 - 14 - 16</td>
<td></td>
</tr>
<tr>
<td>Angle of Pressure</td>
<td>20.00</td>
<td>Degree</td>
</tr>
<tr>
<td>Speed</td>
<td>3000.00</td>
<td>RPM</td>
</tr>
<tr>
<td>Width of gear</td>
<td>36</td>
<td>mm</td>
</tr>
</tbody>
</table>

iii. Unstandard Gears Properties

The reasons of unstandard gears technology as a new gear with most industrial applications are as following [12]:
1. Avoiding it when utilizing teeth at less than 17 under phenomena of cutting.
2. Increasing the tooth root resistance against the stress on the root expose on the fillet region.
3. Reducing the contact ratio among the teeth meshing.

Positive Rack shift coefficient($X_o$) leads to reduce the tooth thickness at tooth tip and to increase it at pitch circle. According to the using Rack shift coefficient value the changing of tooth shape is illustrated in Fig. 2.

(a) Standard gear.  
(b) Unstandard gear.

Fig. 2 Types of gear.

The formulas of unstandard gear with all parameters are as below [13]:
1. The addendum circle diameter can be evaluated as:

\[ D_a = 2(A + m - X_o m) - (D_p)_g \]  

(1)

2. The diameter of root circle tooth can be estimated as:

\[ D_r = (D_p)_g - 2(1.25 - X_o)m \]  

(2)

iv. The gear meshing of pitch circle diameter can be evaluated as:

\[ (D_p)_e = mZ + 2X_0m \]  

(3)

4. the distance among the meshing gears centers can be calculated as:

\[ A = A_o + \dot{X}m \]  

(4)
\[
A_o = m \frac{Z_1 + Z_2}{2} \quad (5)
\]
\[
X = X_1 + X_2 = 2X_o \quad (6)
\]

5. The angle of pressure can be evaluated as:
\[
\alpha = \cos^{-1}(\cos(\alpha_o) \frac{A_o}{A}) \quad (7)
\]

6. The base circle diameter can be calculated as:
\[
D_b = (D_p)_g \cos(\alpha_o) \quad (8)
\]

7. The pitch of circular can be estimated as:
\[
t = m\pi \quad (9)
\]

8. The diameter generation of the circle pitch can be evaluated as:
\[
(D_p)_g = mZ \quad (10)
\]

2.4. Gear Pump Ideal Delivery

The energy method is adopted to express the theoretical gear pump flow rate which consists of a concept of ideal torque. The ideal torque has been generated by the gear pump pressure drop at exit and inlet [14,15] as shown in Fig. 3.

\[
T_1 = b \int_{R_1}^{R_2} \Delta P \cdot R \cdot dR = \frac{\Delta P \cdot b}{2} (R_{12}^2 - R_1^2) \quad (11)
\]
\[
T_2 = b \int_{R_1}^{R_2} \Delta P \cdot R \cdot dR = \frac{\Delta P \cdot b}{2} (R_{22}^2 - R_2^2) \quad (12)
\]

![Fig. 3 Gear pump mesh flow rate.](image)
The energy equation may be expressed to be:

\[ \Delta P \ddot{\theta} = T_1 d\theta_1 + T_2 d\theta_2 \]  \hspace{1cm} (13)

\[ (T_1 + T_2 i) \frac{1}{\Delta P} = \ddot{\theta} \]  \hspace{1cm} (14)

Where: \( \theta_1 \) and \( \theta_2 \) are angle of the rotate driving gear and the angle corresponding rotation of the driven respectively.

\[ i = \frac{Z_2}{Z_1} = \frac{d\theta_2}{d\theta_1} \]

Each gear rotation flow rate can be expressed as:

\[ Q = \pi b (R_{a1} - R_{p1}^2 + i R_{a2}^2 - R_{p2}^2) - 1 - i \frac{t_o^2}{12} \]  \hspace{1cm} (15)

\[ t_o = \pi m \cos \alpha_o \]  \hspace{1cm} (16)

2.5. Types of Gears

i. Standard Gears

The properties of standard gears are formulated as [16]:

\[
\begin{align*}
R_{a1} &= R_{p1} + m \\
R_{a1} - R_{p1}^2 &= 2R_{p1}m + m^2 \\
R_{a2} - R_{p2}^2 &= 2R_{p2}m + m^2
\end{align*}
\]  \hspace{1cm} (17)

There were two identical involutedly external spur gears profile,

\[ D_{a1} = D_{a2} = D_a, D_{p1} = D_{p2} = (D_p)b, Z_1 = Z_2 = Z, \quad i = \frac{Z_1}{Z_2} = 1. \]

Hence eq. (15) is modified for ideal flow delivery as:

\[ Q_\pi = 2\pi b m^2 n \left( Z + \frac{\pi^2 \cos^2 \alpha_o}{12} \right) * 10^{-6} \]  \hspace{1cm} (18)

ii. Unstandard Gears

The external spur gears profile has two identical involutedly for unstandard gear pump as:

\[ \begin{align*}
D_{a1} &= D_{a2} = D_a, D_{p1} = D_{p2} = (D_p)b, Z_1 = Z_2 = Z, \quad i = \frac{Z_1}{Z_2} = 1 \\
D_{p1} &= D_{p2} = (D_p)b, X_1 = X_2 = 2X_o.
\end{align*} \]

Hence eq. (15) is modified for delivery perfect flow as:

\[ (QT)_\pi = n \pi b \left((mZ + mX + m - mX_o - \frac{mZ}{2})^2 - \left(\frac{m(Z + 2X_o)}{2}\right)^2 - \frac{m^2 \pi^2 \cos^2 \alpha_o}{6}\right) * 10^{-6} \]  \hspace{1cm} (19)

a. Contact Ratio

i. Standard Gears Contact Ratio
Standard gears contact ratio may be evaluated as following [17]:

\[
\varepsilon = \frac{2\sqrt{R_a^2 - R_b^2} - A \sin \alpha_o}{t_o} \tag{20a}
\]

\[
t_o = \pi m \cos \alpha_o \tag{20b}
\]

### ii. Unstandard Gears Contact Ratio

Unstandard gears contact ratio may be evaluated as following:

\[
R_a = (mZ + mX + m - mX_o - \frac{mZ}{2})^2 \tag{21}
\]

\[
\alpha = \cos^{-1} \cos \alpha_o \frac{A_o}{A} \tag{22}
\]

\[
R_b = mZ \cos \alpha_o \tag{23}
\]

\[
A = A_o + Xm = mZ + Xm \tag{24}
\]

Substitute Equations from (21) to (24) in eq. (20) as following:

\[
\varepsilon_c = \frac{2\sqrt{(mZ + mX + m - mX_o - \frac{mZ}{2})^2 - (mZ \cos \alpha_o)^2 - (mZ + m)(\cos^{-1} \cos \alpha_o)} \frac{mZ}{mZ + Xm}}{m\pi \cos \alpha_o} \tag{25}
\]

### b. Factor of Pulsation Flow Rate

#### i. Standard Gear pump

There are two identical involutedly profiles and trapped volume backlash of liquid between the teeth. The flow factor of pulsation is expressed as [18]:

\[
\delta_2 = \frac{\pi^2 \cos^2 \alpha_o}{4[Z + 1 - \frac{\pi^2 \cos^2 \alpha_o}{12}]} \tag{26}
\]

#### ii. Unstandard Gear pump

There are two identical profiles involutedly, volume of trapped liquid and backlash between the teeth. The flow factor pulsation is expressed as:

\[
\delta_1 = \frac{\pi^2 \cos^2 \alpha_o}{4[(mZ + mX + m - mX_o - \frac{mZ}{2})^2 - (mZ + 2X_o)/2 - \frac{\pi^2 \cos^2 \alpha_o}{12}]} \tag{27}
\]

### 3. Results and Discussion

#### 3.1. Ideal Flow Rate
The ideal flow rate is considered as one of the significant of gear pump properties, therefore, the probability of the flow rate increasing is investigated. Figure 4(a) illustrates the effect of teeth number on the flow rate. It can be seen that the module gears square have proportional with flow rate, the teeth width and the pressure angle of gear as shown in Fig. 4(a, b, c and d) respectively. It can be noted that the using of unstandard gear with Rack shift coefficient of 0.5 instead of standard gear has led the flow rate to increase. Figure 5 indicates that reduce number of teeth and increase the module to increase the flow rate with small size of pump. It can be seen that the decrease of the number of teeth is led to increase of the pressure angle.

![Graphs showing flow rate vs module, flow rate vs number of teeth, flow rate vs width of gear, and flow rate vs pressure angle.](attachment:image)

**Fig. 4** Parameters affected on flowrate.

**Fig. 5** Unstandard gear pressure angle with teeth number.

### 3.2. Trapped Volume

For the other meshing teeth pair, the enclosed volume among the contact points has been created at the ends of meshing among pair contact teeth. An increase of pressure due to decrease the enclosed space which happened as a result of trapped liquid inside enclosed volume [19]. Therefore, it was used with a few contact ratios.

It was observed that there is proportional contact ratio with teeth number as shown in Fig. 6(a). The relation between the standard gear contact ratio and trapped volume is indicated in Fig. 6(b). Whilst, the relation between unstandard gear contact ratio and trapped volume is illustrated in Fig. 7. Due to decrease in contact ratio, the unstandard gears have been used. In order to reduce the volume of trapped liquid, the unstandard gears have been used.
3.3. Pulsation Flow Rate Factor

The flow rate of pulsation has get from gear pump is in the pulses form. It was led to influence of the pump efficiency with vibrations inside the pump [20]. For unstandard gear pump, the increase of teeth number has led to decrease the factor flow rate pulsation as shown in Fig. 8(a). And decrease of this factor is led to increase of the pump efficiency. The comparison indicates that it is better to use the unstandard gear than standard gear as shown in Fig. 8(b).

It is necessary to indicate the increase of pump flow rate with the change of the profile shift coefficient and the bending strength of the teeth. The use of dimensionless factors to describe gear tooth geometry appears to be a strong appeal of gear engineers. The
addendum modification, rack shift, or profile shift factor has several mathematical definitions in the U.S. Most European documents use a specific definition, based on a theoretical “zero backlash” gear pair in tight mesh at the nominal center distance. This conclusion is logical in view of the fact that an increase in the addendum diameter led to an increase in flow rate. The approval that the increase of the teeth number leads to an increase in flow rate is contained in the study [5].

4. Conclusions

The most widely source adopted of hydraulic applications power is the external gear pumps due to allow a good performance and low manufacturing costs. This study investigates the using of unstandard gears and the gear pumps performance affected. The following conclusions are drawn from this analysis.

- It is concluded that there is a high flow rate due to the unstandard gear pump used as compare to the standard gear type.
- The using of unstandard gear has led to decrease the volume of trapped liquid and the contact ratio among meshing of teeth too.
- The factor of pulsation flow rate is reduced as the teeth number increase which, leads to stabilize of flow rate pulsation.

References