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Research Paper

Effects of Gear Tooth Helix Angle on Pressure Pulsation Characteristics of External Gear Pump in Highly Pressurized Regions

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Abstract—In this research, the effect of gear tooth helix angle on external gear pump CFD characteristics is studied. Two different external gear pump models using spur and helical gears are simulated, and their pressure generation capabilities and pressure pulsation characteristics are compared. The monitoring points used for data analysis were placed at the high-pressure points of the pump, and iterative mathematical algorithms were applied for the analysis of the data. The results of this study showed that it was determined that the helix angle has a significant effect on pressure generation and the pulsation characteristics of the external gear pump. During general data regression and analysis, not only the comparison of spur and helical external gear pumps but also their pulsating values were investigated at different points in the flow domain, and their change intensity, results, and discussions were discussed in detail.

Keywords— Spur gear pump pressure pulsation, Helical gear pump pressure pulsation, Spur gear pump flow ripple, Helical gear pump flow ripple, External gear pump flow fluctuation.

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1. Introduction

Because of their straightforward design, compact size, excellent dependability, potent anti-pollution capabilities, and effective self-priming, external gear pumps are widely employed in industry [1]. However, the operating performance of the gear pump will be impacted by the pressure pulsation, cavitation, and noise caused by fluid trapped in the pump [2]. For the gear pump to operate more efficiently and with less vibration and noise, it is important to investigate the elements that affect the pressure pulsation in the trapped area of the gear pump. By establishing monitoring points at various places, a group of researchers was able to get pressure pulsation results [3]. To track pressure changes on the teeth in real time, other researchers adopted a tooth pressure monitoring technique [4]. Helix angle, gear radial clearance, and speed were investigated to determine their effects on pressure pulsation [5]. They investigated several measurement techniques; however, they did not take into account how gear factors would affect the pressure pulsation at various positions. One of the most rigorous methods for evaluating the pressure ripple caused by a hydraulic pump in a hydraulic system is the experimental method, which evolved from the "secondary-source" method first proposed [6]. Accordingly, the hydraulic pump is represented as a source of flow (called the "source flow ripple") and a source of impedance (called the "source impedance"). A secondary pulsation source can be used to quantify source flow ripple and source impedance, two crucial characteristics that define the fluid-borne noise of a hydraulic pump [7].

The approaches put out by other researchers ([8], [9], [10],[11]) are two instances of similar experimental procedures that other researchers have developed for characterizing hydraulic pumps. A group of researchers conducted supplementary research too ([12], [13], [14]).

Vibration from pressure pulsation, which is brought on by an imbalanced flow rate of hydraulic fluid from the pump to the system, accelerates the wear and tear on working parts, reduces the precision of positioning receivers, and increases noise emission ([15],[16],[17]).

The variation in temporary flow output causes capacity fluctuations in external gear pumps with similar gear wheels [17].

Other studies also obtained pumping pressure pulsation curves ([18], [19]) and examined them in terms of duration and frequency. The time analysis was done to identify the peak-to-peak value of pumping pressure that affects the fatigue wear of hydraulic system components and is responsible for increasing vibration and noise levels.

In general, although there are many gear types, spur and helical gears are the most widely used in the industry. Helical gears are spur gears whose teeth are bent at a certain angle (helix angle). Helical gears are most similar to spur gears in their geometrical characteristics and shape. Their application areas are very similar and can substitute for each other in many applications. From this viewpoint, which of these two is more suitable to be used in which application has always been the main topic of the investigations.

External gear pumps are the most popular among positive displacement pumps, and today, in industrial applications, not only in these pumps but in all positive displacement pumps, pressure pulsation and its negative effects are among the most important problems that need to be solved. Pressure pulsation not only causes fluid-borne noise and vibration in fluids but also creates changing pressure values on various mechanical parts of the EGP, which in turn cause mechanical vibration and noise. In the EGP sample, these pulsating pressure values cause continuous vibration in the shafts of the driven and driving gears, in addition to the effects created on the internal wall of the main body of the pump and outlet pipe. Due to the high outlet pressure values in external gear pumps, the magnitude differences at different points between these values, and the fact that these pressure values all pulsate at the same time, the pressure-forming process in EGPs and its study are complicated processes. It is clear that the geometry has serious effects on the CFD characteristics of the designed pump, and the helical angle of the gear teeth is considered the main influencing geometrical factor in this study. Therefore, the CFD characteristics of two different EGP models with the same geometrical parameters using spur and helical gears and the pressure changes caused by this helix angle are studied by means of simulation. Here, both average values of pressure (pressure generation capabilities) and pulsation characteristics are compared. The regions where the monitoring points are located for the study of pressure values are typically chosen mainly for the points where high pressure is observed. There are 5 monitoring points in total, and two of them (Probes 1 and 2) are located in the control volumes of the EGP, and the next two (Probes 3 and 4) are located in the outlet region where the pressure is much higher than the control volume. In addition, the last monitoring point (Probe 5) is placed in the region where the gears enter the meshing. The main reason for studying this part separately is that the pressure created at this point creates excessive pressure on the gears, which causes misalignment of the gear shafts.

2. Numerical Setup

The modeled external gear pump was simulated using Dassault Systemes "Simulia XFlow" software, which is among the most suitable options for positive displacement pumps. 2 bar total pressure was applied at the inlet as a boundary condition, and at the outlet, 0 bar static pressure was applied as the free outlet opening. Water with an inlet temperature of 20 °C was selected as the working medium (Newtonian). In addition, reference density = 1000 kg/m^3, dynamic viscosity = = 0.0008.9 Pa·s, thermal conductivity = 0.598 W/m·K and specific heat capacity: 4184 J·kg^{-1}·K^{-1} were accepted. Transient simulation was applied as flow type, and the time step was automatically set to be t = 0.00005012531 by the algorithm of the software for the selected parameters. Flow was simulated using Wall Adapting Large Eddy-Viscosity (wale) turbulence model. Pump geometry details can be found in the following tables:

Table 1: Pump casing parameters

Wall thickness	w	10 mm
Inlet pipe inner diameter	$D_{in\ 1}$	60 mm
Inlet outer diameter	$D_{in\ 2}$	65 mm
Inlet pipe length	L_{in}	90 mm
Outlet pipe inner diameter	$D_{out\ 1}$	60 mm
Outlet pipe outer diameter	$D_{out\ 2}$	65 mm
Outlet pipe length	L_{out}	90 mm
Casing inlet circle diameter	$D_{C\ in}$	80.2 mm
Radial tip clearance	c	0.187 mm
Distance between center of gears	L_c	65.45651188 mm

Table 2: Gear parameters

RPM	n	1800 rpm
Outer circle diameter	$D_{out\ 3}$	79.826 mm
Inner circle diameter	$D_{in\ 3}$	60 mm
Top Land Width	b	3 mm
Number of teeth	z	10
Body thickness	t	75 mm
Helix angle	θ	18 deg

As mentioned earlier, the monitoring points were placed in the regions with the highest pressure and they can be observed as follow:

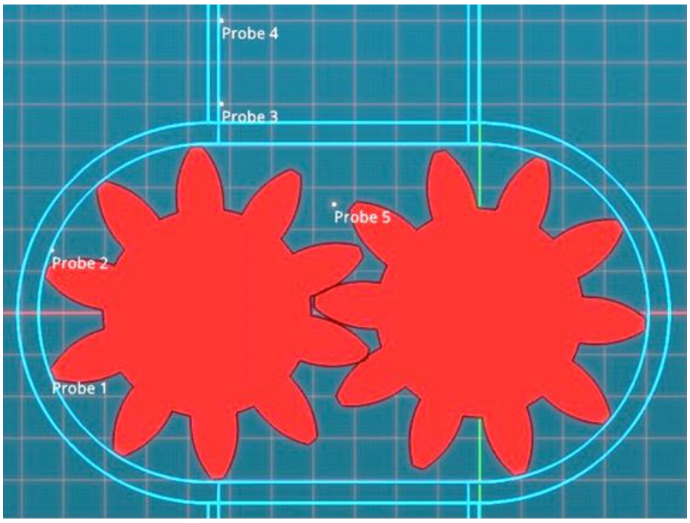

Figure 1: Spur EGP Monitoring Points

3. Simulation Results

The results of the simulation can be seen through the following description and graphs:

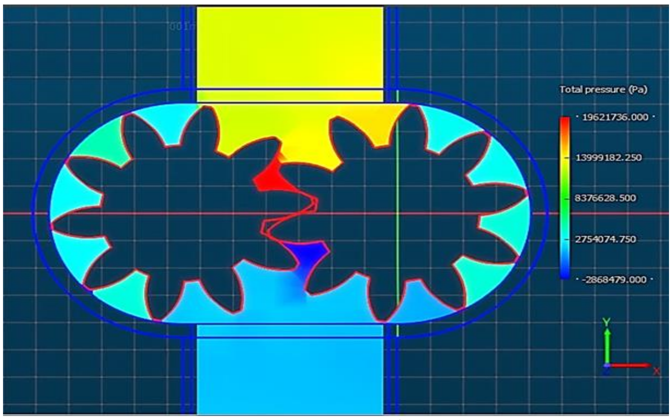

Figure 2: Spur EGP pressure forming process

Spur EGP Pressure Pulsation Plots:

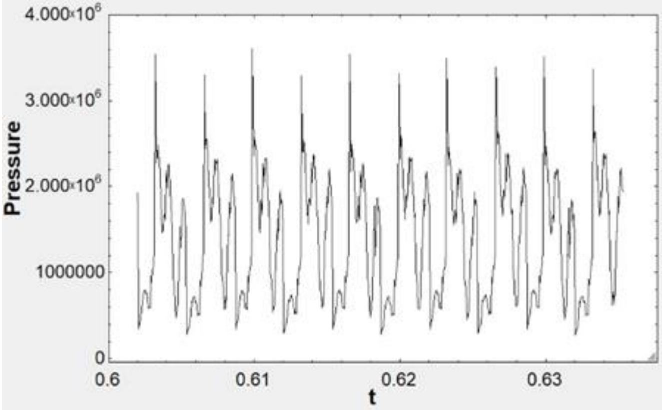

Figure 3: Probe 1 gear one revolution (0.033s)

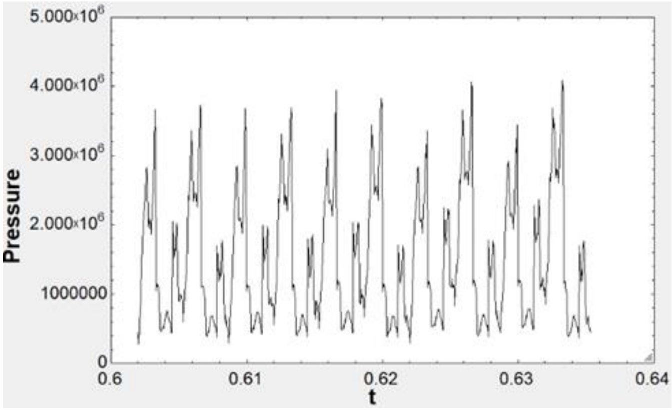

Figure 4: Probe 2 gear one revolution (0.033s)

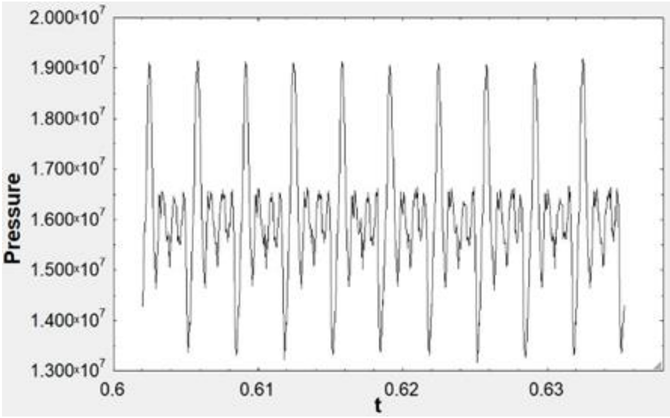

Figure 5: Probe 3 gear one revolution (0.033s)

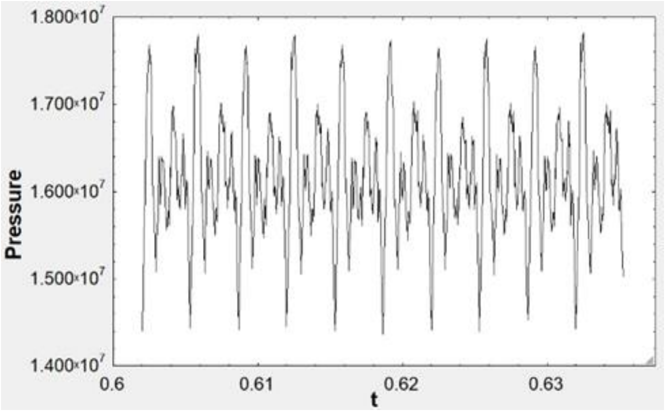

Figure 6: Probe 4 gear one revolution (0.033s)

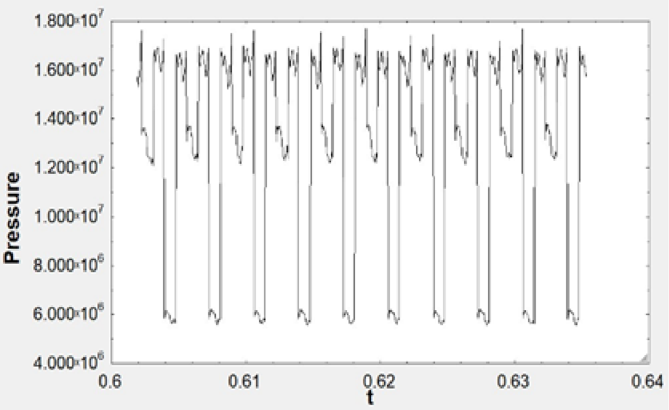

Figure 7: Probe 5 gear one revolution (0.033s)

Spur EGP Frequency Domain Data:

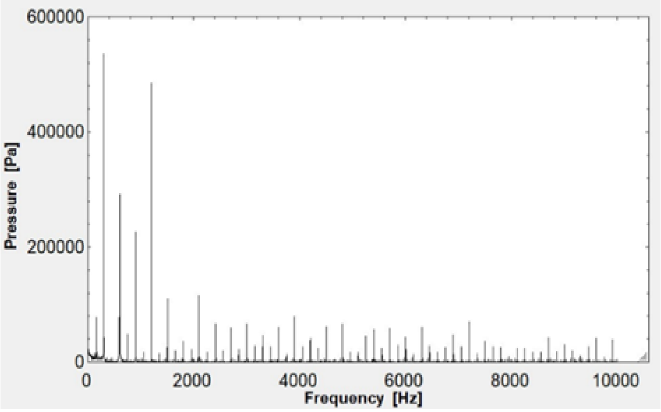

Figure 8: Probe 1 frequency domain

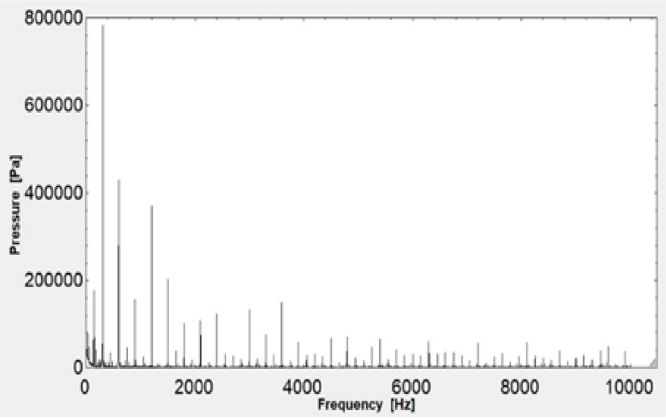

Figure 9: Probe 2 frequency domain

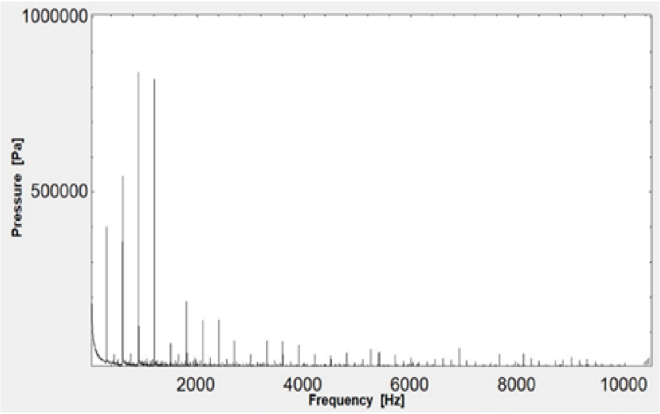

Figure 10: Probe 3 frequency domain

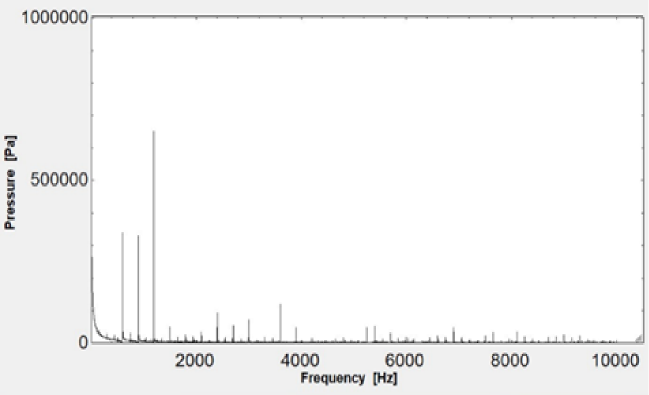

Figure 11: Probe 4 frequency domain

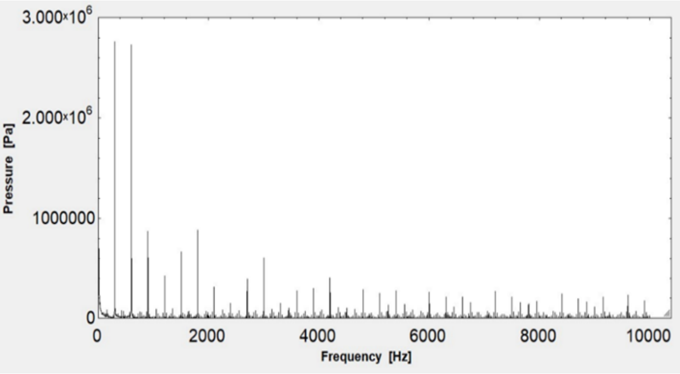

Figure 12: Probe 5 frequency domain

The Helical External Gear Pump was simulated in the same numerical setup as the spur external gear pump, and the only difference is that a helical gear was used instead of a spur gear. The results of the simulation can be seen through the following graphs and plots:

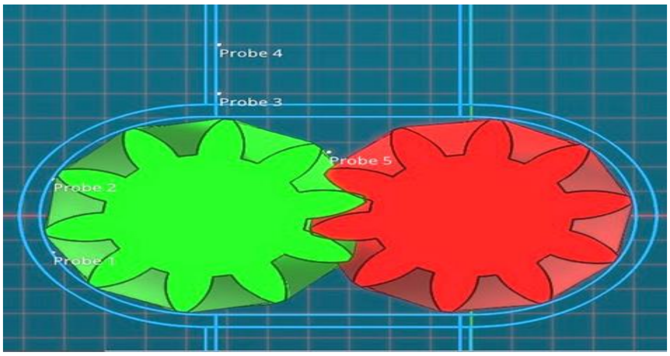

Figure 13: Helical EGP monitoring points

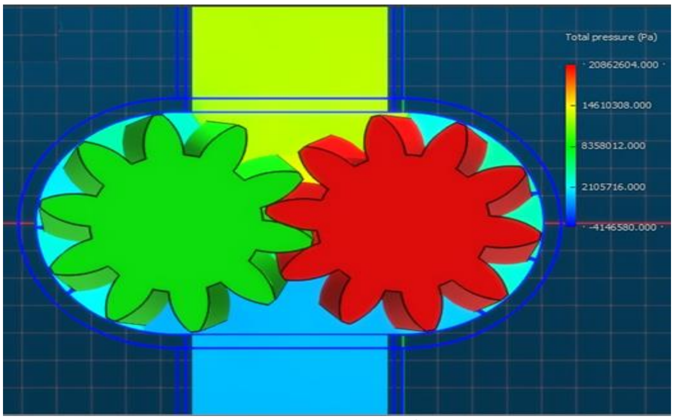

Figure 14: Helical EGP pressure forming process

Helical EGP Pressure Pulsation Plots

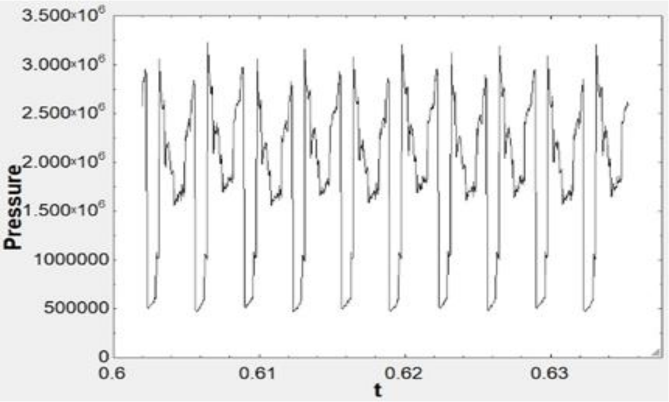

Figure 15: Probe 1 gear one revolution (0.033s)

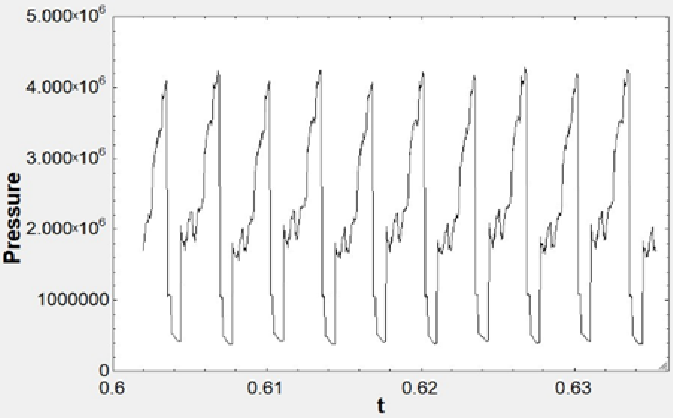

Figure 16: Probe 2 gear one revolution (0.033s)

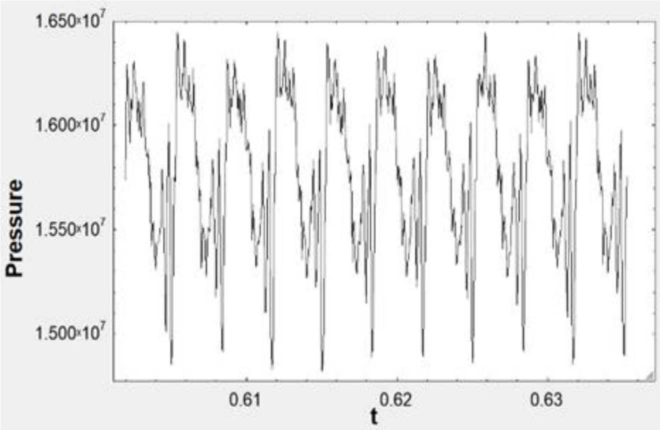

Figure 17: Probe 3 gear one revolution (0.033s)

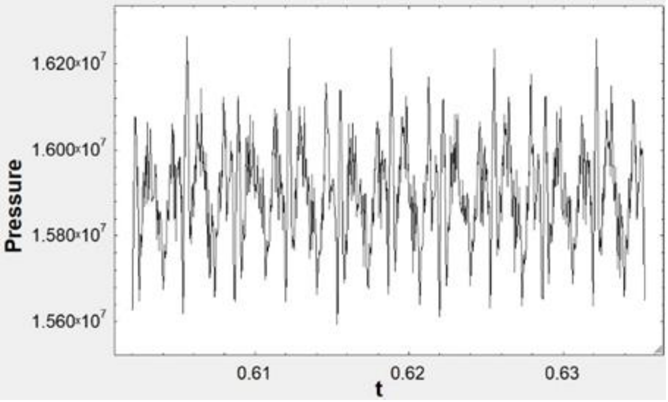

Figure 18: Probe 4 gear one revolution (0.033s)

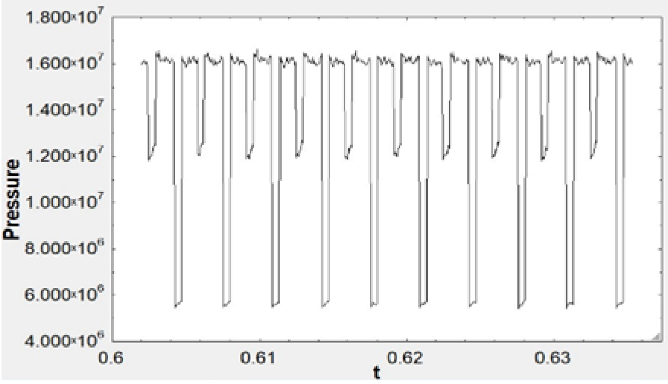

Figure 19: Probe 5 gear one revolution (0.033s)

Frequency Domain Data

Frequency domain graphs obtained using Fast Fourier transform of the above data can be seen as follow:

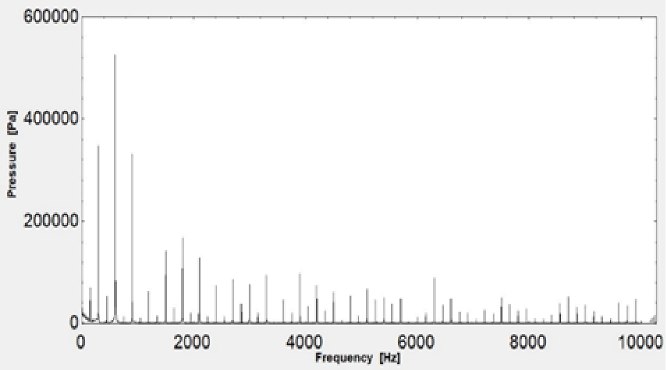

Figure 20: Probe 1 frequency domain

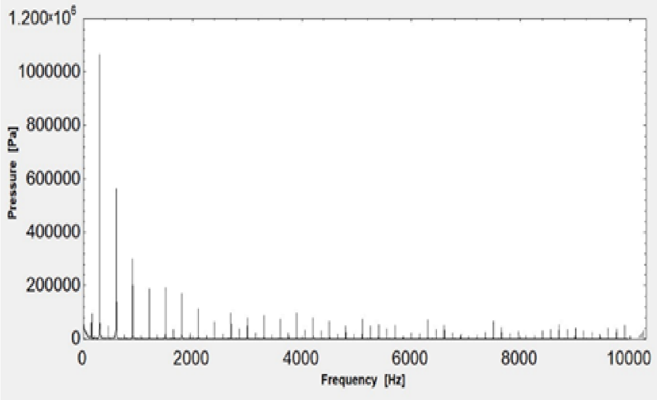

Figure 21: Probe 2 frequency domain

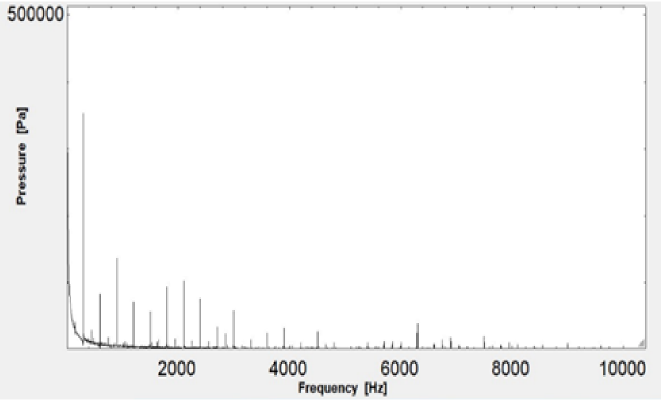

Figure 22: Probe 3 frequency domain

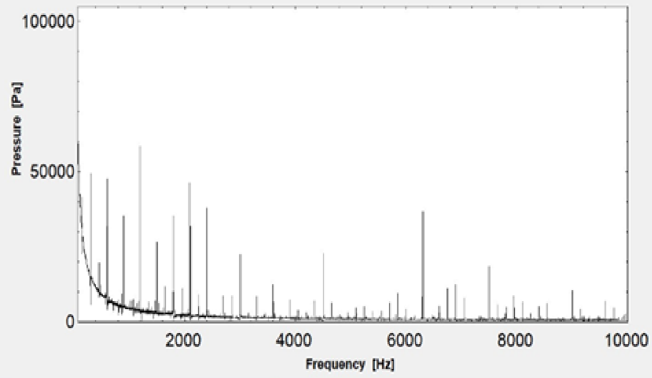

Figure 23: Probe 4 frequency domain

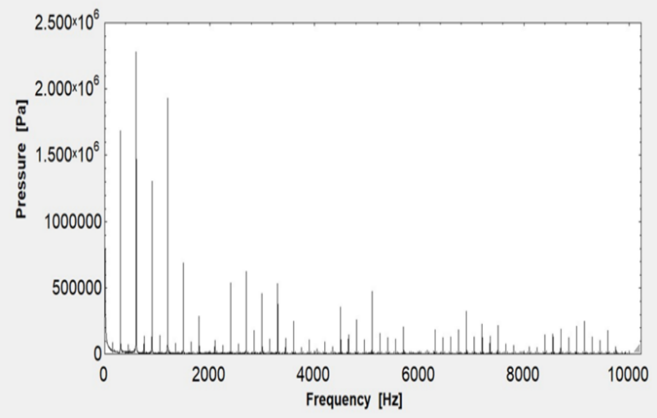

Figure 24: Probe 5 frequency domain

Non- Linear Least Squares Regression

As can be seen from the graphs, in accordance with the nature of positive displacement pumps, pressure values in External Gear Pumps also pulsate in a serious way, and Non-Linear Least Squares Regression is the most effective mathematical method to find the average value of time domain graphs where the values change in this intensity. Engineering Equation Solver that we used in this study for data regression can also apply the Line Search method and related algorithms to obtain more accurate results. Since every revolution of gear (360 degrees) is repeated throughout the entire time domain, the data regression of this part is implemented. The data regression results of 10 probes can be seen as follow:

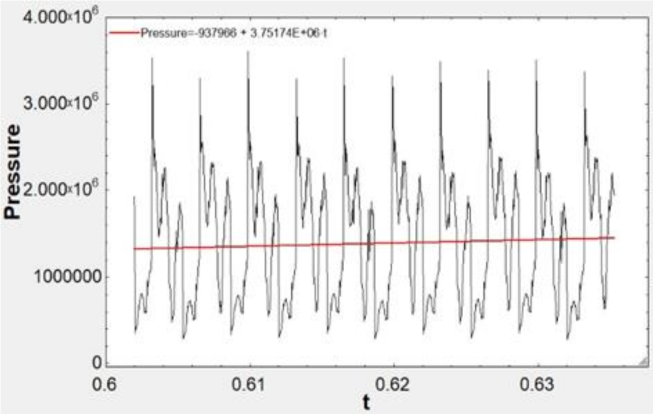

Figure 25: Probe 1 Spur EGP

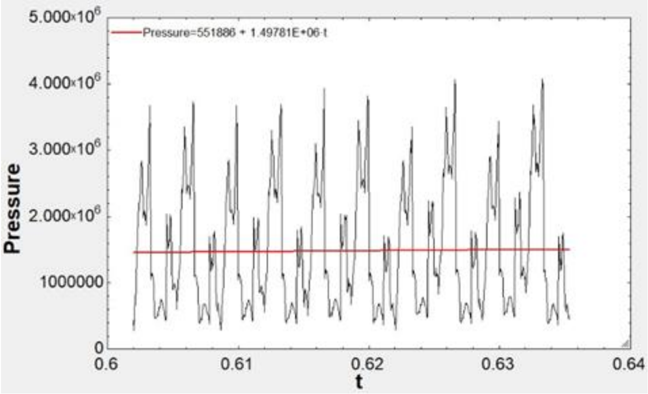

Figure 26: Probe 2 Spur EGP

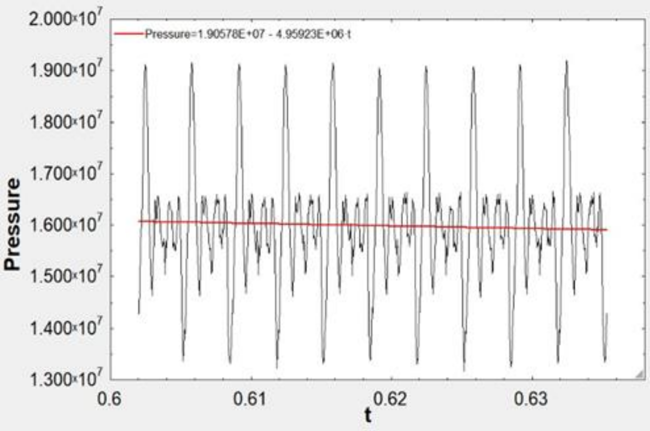

Figure 27: Probe 3 Spur EGP

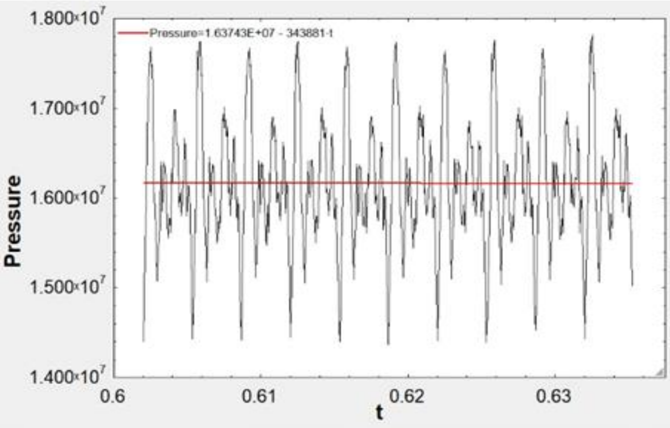

Figure 28: Probe 4 Spur EGP

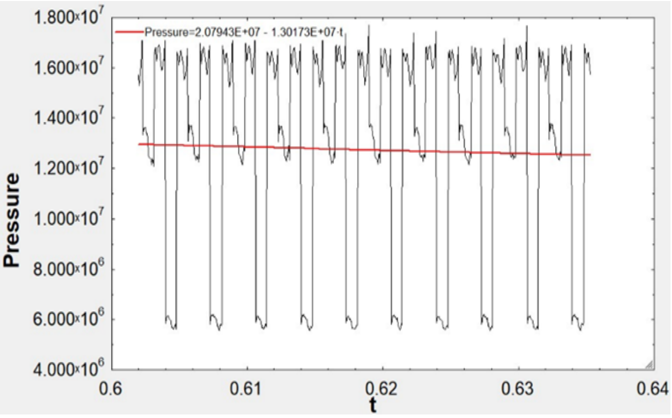

Figure 29: Probe 5 Spur EGP

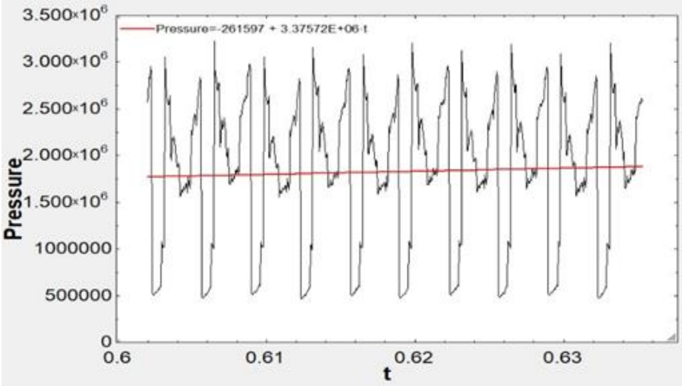

Figure 30: Probe 1 Helical EGP

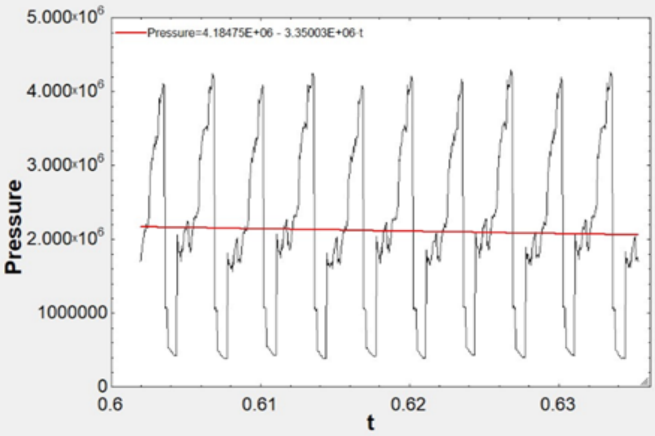

Figure 31: Probe 2 Helical EGP

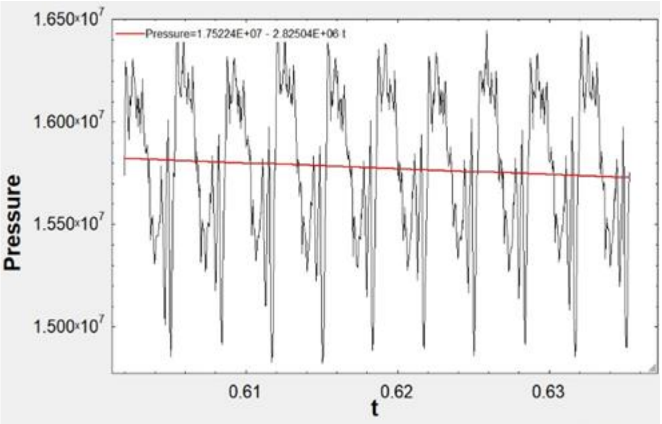

Figure 32: Probe 3 Helical EGP

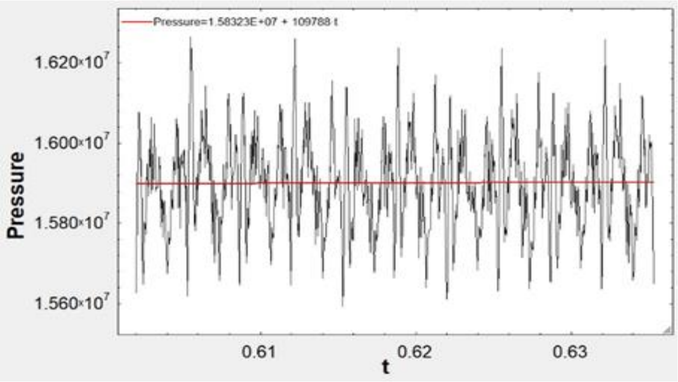

Figure 33: Probe 4 Helical EGP

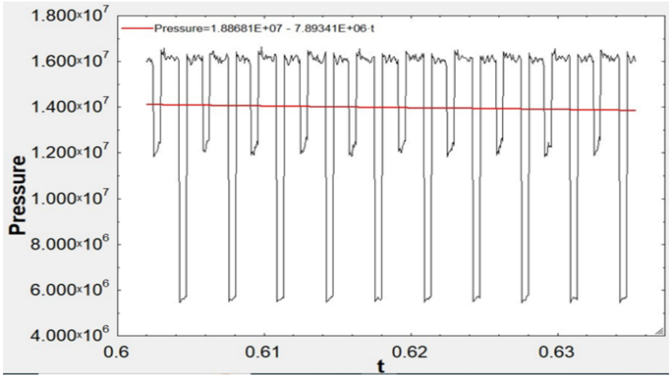

Figure 34: Probe 5 Helical EGP

4. Conclusion

As a result of the research, it was determined that the helix angle has a significant effect on the pressure generation and pressure pulsation characteristics of the external gear pump. During general data regression and analysis, not only the comparison of spur and helical external gear pumps but also their pulsating values at different points in the flow domain and their change intensity were investigated.

- In both spur and helical EGPs, starting from the control volume to the outlet port, at the monitoring points (Probes 1, 2, 3, and 4), the average pressure continues to increase characteristically for all EGPs, and for spur and helical EGPs, the intensity of this increase is almost the same, but this similarity is not observed in the pressure pulsation values. In Spur EGP, the pressure pulsation values are high at the points within the control volume (Probes 1 and 2), but at Probe 3 near the outlet port (although this point is not within the control volume), this value is higher, and as the flow moves in the direction of the outlet port (Probe 4), the pressure pulsation starts to decrease. In the helical EGP, the pressure pulsation is high when flow is inside the control volume, but it decreases seriously when it leaves the control volume, so it can be seen that among the first 4 monitoring points in the spur EGP, the max pressure pulsation occurs in Probe 3 (outside the control volume), and for the helical EGP, the max pressure pulsation occurs within the control volume (Probe 2).

- At the points in the control volume (Probes 1 and 2), the pressure fluctuation peak-to-peak values in the helical and spur EGPs are approximately the same, but as flow passes from the flow control volume to the outlet port (Probes 3 and 4), the spur EGP peak-to-peak values increase significantly compared to the helical EGP (Probes 3 and 4). Accordingly, helical EGPs are a more suitable choice from the point of view of pressure-pulsation-based vibration.

- At the point where the gears enter meshing in the outlet part of the spur and helical EGPs, the pressure peak-to-peak value difference is not significant (6%). From this viewpoint, the difference in torque ripple (one of the main reasons for mechanical shaft vibration) caused by pressure pulsation at this point does not significantly differ.

- At the points in the Control Volume (Probes 1 and 2), the average pressure generated in the helical EGP is higher (29%) than the spur EGP, but as it approaches the outlet port (Probes 3 and 4), this difference decreases and the average pressure becomes nearly the same and this situation also occurs in the gear teeth meshing region (Probe 5). In this sense, instead of the advantage of vibration and noise based on pressure pulsation, the pump casing wall is exposed to more stress in helical EGP.

In both spur EGP and helical EGP, when the flow within the control volume passes from the initial teeth to the teeth close to the outlet port (from Probe 1 to Probe 2), the amplitudes in the pressure frequency domain increase, and after leaving the control volume, as it moves from the outlet port to the further point (from Probe 3 to Probe 4), the amplitude starts to decrease. In the spur EGP, when the flow passes through the points Probes 1, 2, 3, and 4, the amplitude changes gradually, but during the transition between the points in the helical EGP, this difference is quite intense. In addition, in spur EGP, Probe 5's amplitude is 22% higher than helical EGP.

5. Conclusion and Future Scope

In the future aspect of the work, not only the helix angle of the gear tooth, but also other important parameters will be subjected to multi-optimization at the same time to minimize the pressure pulsations, as well as fluid-borne noise & vibrations, with variations determined in different intervals. These parameters will include top land width, pressure angle, number of teeth and other parameters. The optimization will be carried out by the response surface method. During the optimization, the results of the fluid-structure interactions of each case will be computed separately. And in this way, the transient stresses caused by high pressure in the pump supports and also in the inlet-outlet pipes will be measured at different time intervals, and the reliability factors of the work will also be taken into account.

Data Availability
None

Conflict of Interest
Author declares no any conflict of interest.

Funding source

No funding source exists during the research study.

Author's contribution

All contributions are made by the sole author

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None

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