

Performance Analysis and Optimization of Journal Bearings in Bidirectional Gear Pump

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Abstract - In the endurance test of the gear pump for engineering machinery, the efficiency decreased and the bearing failed after running-in for 50 hours. After analyzing the failure reasons, it was found that the bearing's bearing capacity is insufficient. The inner surface coating of the journal bearing is changed from polytetrafluoroethylene (PTFE) to polyetheretherketone. The end face frictional wear test machine is used to test the two coating materials. The low-speed test, high-speed test, and heat resistance test are conducted. The test results show that the bearing material of polyetheretherketone sliding bearing is superior to the polytetrafluoroethylene (PEEK) journal bearing in terms of running-in time, friction coefficient, contact temperature, and heat resistance. The new material journal bearing is assembled into the entire pump and subjected to endurance test again. After running-in for 100 hours, it is found that the efficiency did not decrease significantly. After disassembling the pump, it is found that the journal bearing and other friction parts in the pump had not failed. The test shows that polyetheretherketone coating material can effectively improve the bearing capacity of the journal bearing and improve the life of the gear pump.

Keywords - journal bearing, durability test, friction test, gear pump

I. INTRODUCTION

Bidirectional gear pumps are widely employed in hydraulic power transmission systems, and their journal bearings play a pivotal role in ensuring operational stability and volumetric efficiency. The service life of these bearings is governed by a multiplicity of factors—encompassing material properties, lubrication regimes, applied loads, and rotational speeds. A systematic investigation of bearing life not only enhances the reliability of gear pumps but also reduces maintenance expenditure and elevates overall pump performance. The underlying mechanism involves the formation of a convergent wedge between the shaft and the bearing bore. Hydraulic oil is drawn into this wedge at high rotational speeds, generating hydrodynamic pressure that elevates the gear shaft. The resulting oil-film pressure counterbalances the external radial load, while frictional resistance remains confined to viscous shear within the lubricant.

Research on gear-pump journal bearings has mainly focused on the following aspects. Reference [1] investigated a dynamic oil-film thickness measurement method for fuel pumps based on ultrasonic technology. Reference [2] developed a numerical model for the journal bearings in fuel gear pumps to determine the journal's equilibrium position

and the pressure distribution. Reference [3] presents a journal-bearing test platform that measures film thickness using ultrasonic transducers embedded in both the bearing and the rotating shaft. This ultrasonic technique offers a non-invasive, direct measurement of the shaft–bearing interface, enabling the analysis of phenomena such as squeeze-film action. The study shows that squeeze time decreases with increasing shaft speed, applied load, and bearing temperature. In Reference [4], a CFD-based transient radial-motion model is integrated to elucidate the lubrication failure mechanism of aviation gear-pump bearings under high-eccentricity, high-temperature, and low-viscosity condition. In Reference [5], the lubrication failure mechanism of fuel-pump journal bearing under high-temperature, high-pressure, and low-viscosity conditions is investigated. In Reference [6], the bearing transient lubrication model incorporates the coupled effects of shaft misalignment and surface roughness, enabling analysis of pump-bearing system characteristics—including internal pump flow, bearing lubrication, and component cavitation. Reference [7] proposes a real-time temperature-compensation method for oil-film thickness measurement. Reflections from the substrate–coating interface are used to compensate for temperature-induced variations in phase increment and amplitude attenuation. An additional experiment employing a substrate–coating–air structure is conducted to pre-calibrate the temperature effect on the phase shift introduced by the coating. Combining “self-calibration” with “pre-calibration” yields a comprehensive temperature-compensation strategy.

Reference [8] developed a numerical model for the analytical design of fuel-pump journal bearings. The model determines the equilibrium position of the journal under both partial- and full-load steady-state operation, accounting for the significant influence of elastic deformation on the lubricant-film pressure distribution. It can be used to characterize the pressure distribution within the lubricant under various bearing designs and operating conditions. Reference [9] investigated the temperature rise of journal bearings in circular-arc gear pumps with and without herringbone grooves, analyzing the influence of rotational speed and outlet pressure on the rise. The results show that machining herringbone grooves in the bearing effectively reduces temperature increase. Reference [10] developed an elastohydrodynamic lubrication (EHL) model for an aviation gear-pump journal bearing that accounts for the elastic deformation of the bearing shell. Adaptive Kriging sampling

combined with the AK-IS method was employed to evaluate the reliability and sensitivity of the hydrodynamic lubrication characteristics. The results show that the peak pressure decreases by 15.04 % when the elastic deformation of the bearing shell is considered, compared with the rigid-shell case. Reference [11] developed a thermo-hydrodynamic lubrication analysis model for bearings and investigated the influence of shear-thinning on bearing lubrication performance under various operating conditions. The results reveal that shear-thinning has a positive effect on bearing lubrication characteristics under light-load conditions, whereas it exhibits a negative effect under heavy-load conditions. Domestic and international literature on prolonging the service life of gear-pump sliding bearings remains scarce. Consequently, the present study adopts an experimental approach to systematically examine the problem, with direct reference to the failure modes observed in real-world engineering applications.

During durability testing of a bidirectional gear pump, journal bearing failure was observed. Analysis confirmed that the root cause is insufficient bearing load capacity. To address this, an optimization approach involving improved coating materials is proposed. PEEK journal bearings are selected as the alternative solution. Comparative tests between PTFE and PEEK journal bearings are conducted on a face wear testing machine. After testing, the PEEK bearings are reassembled into the gear pump and subjected to durability testing again. The results met the durability test requirements.

II. STRUCTURE OF GEAR PUMP JOURNAL BEARING

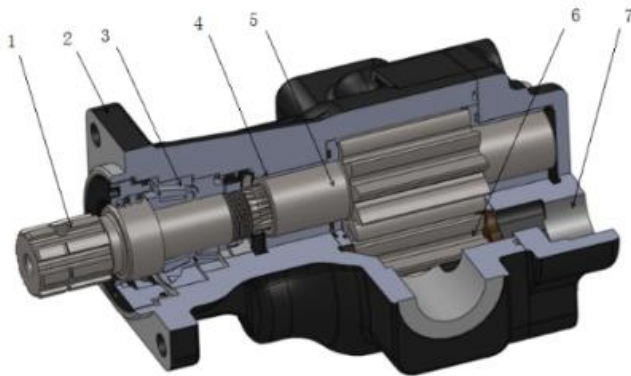


Figure 1 Structure of the bidirectional gear pump

The bidirectional external-gear pump serves as the hydraulic power source for the actuation of the lift cylinders in a tipper-truck hydraulic circuit. Figure 1 illustrates its sectional assembly: 1—drive shaft; 2-front end cover; 3-outboard rolling-element bearing; 4- journal bearing; 5-drive gear; 6-driven gear; 7-rear end cover. Table 1 summarizes the nominal performance parameters of the pump.

Table 1 Performance parameters of the gear pump	
Parameter	value
Displacement	100.1 mL/r
Rated speed	2000r/min
Rated pressure	20Mpa
Lubricating oil	L-HM46: GB/T 7631.2-2003
Module	4.5
Number of teeth	11

Pressure angle	28°
Center distance	49.5

Figure 2 indicates that the journal bearing is formed by rolling, with a lubrication groove milled at the central seam; its inner diameter is 32 mm, outer diameter 36 mm, and length 35 mm.



Figure 2 Exterior view of journal bearing

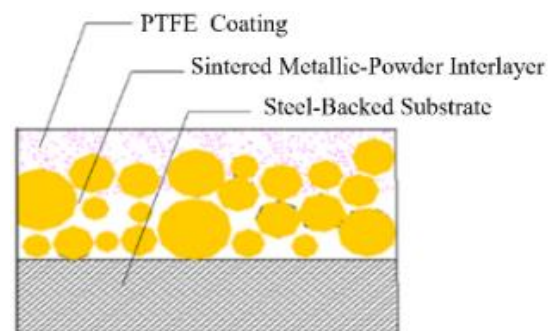


Figure 3 Structure of journal bearing

As shown in Figure 3, the gear-pump journal bearing is composed of three layers: an outer shell made of thin steel plate as the substrate, a middle layer of sintered metal powder, and an inner surface coated with an organic anti-friction layer of polytetrafluoroethylene (PTFE).

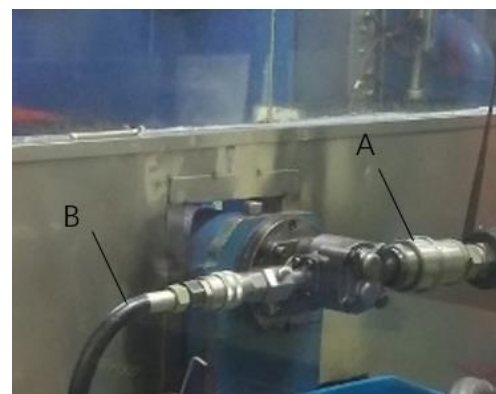


Figure 4 Test connection diagram

II GEAR PUMP DURABILITY TEST

In accordance with the Chinese standard JB/T 7041 for hydraulic gear pumps, a durability test is carried out on the hydraulic test bench shown in Fig. 4 (A: suction line; B: pressure line). The test run at an overload pressure of 23 MPa and a rotational speed of 2 000 r/min. According to the standard, the pump is deemed to have passed the durability test only after 100 h of continuous overload operation. Figure 5 presents the efficiency–time curve recorded during the test. During the first 40 h the volumetric efficiency fluctuated around 95 %. After 40 h the efficiency began to decline, falling to approximately 90 % at the 50-h mark, indicating the onset of component failure. Consequently, the test was stopped at 50 h and the pump was disassembled for inspection; the findings are shown in Figs. 6 and 7.

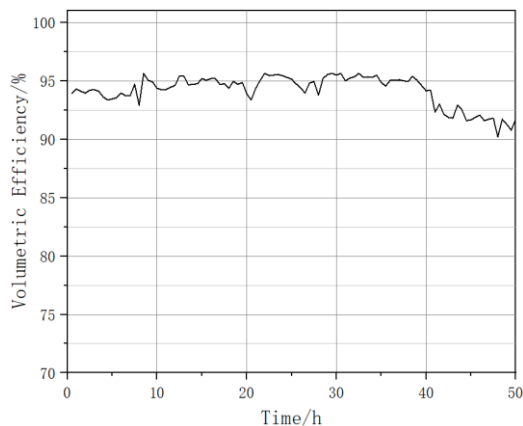


Figure 5 Volumetric Efficiency Curve of the Gear Pump with PTFE Journal Bearings

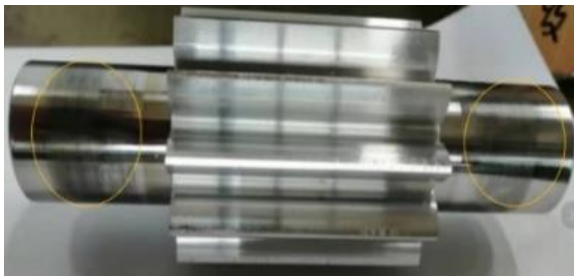


Figure 6 Failure morphology of the gear shaft



Figure 7 Failure morphology of the journal bearing

Figure 6 presents the failure morphology of the gear-pump shaft. The shaft regions in contact with the journal bearings at both ends exhibit severe wear and black discoloration, as highlighted by the elliptical areas, indicating failure of the journal bearings. Figure 7 shows the driven-gear journal bearing in rear cover of the pump. The bearing surface that interfaces with the gear-pump shaft displays pitting and black discoloration, both of which are indicative of bearing failure.

Three potential causes of bearing failure are identified: contaminated lubricant, insufficient lubrication, and inadequate load-bearing capacity. Since the test-rig reservoir have just undergone oil filtration prior to the test, contamination can be ruled out. Under the operating conditions of 23 MPa and 2 000 r/min, the measured flow rate through each journal bearing is 0.4 L/min, which satisfies the lubrication requirement. Consequently, the primary cause of journal bearing failure is determined to be insufficient load-bearing capacity.

III. VERIFICATION OF THE JOURNAL BEARING

Enhancing the load-carrying capacity of the journal bearing can be pursued via three routes: enlarging the bearing dimensions, upgrading the hydraulic fluid, and optimizing the bearing material.(1) Increasing the bearing size would enlarge both the overall dimensions and the weight of the gear pump, conflicting with the stringent installation constraints in construction machinery; this option is therefore impractical.(2) Improving hydraulic-oil performance would require the procurement of custom-formulated fluids with superior anti-friction and anti-wear additives, raising the OEM's costs and is thus not recommended.(3) Employing a high-performance bearing material allows the load capacity to be raised without altering either the bearing/gear geometry or the fluid type. Consequently, poly-ether-ether-ketone (PEEK) is selected as the internal coating for the journal bearing. To compare the performance of PEEK and polytetrafluoroethylene (PTFE) coatings, tribological and thermal-resistance tests were conducted on both materials using a friction-and-wear test rig.

A. Tribological Testing

To benchmark the tribological performance of the newly selected PEEK material against that of PTFE, comparative tests are conducted on an HDM-20 face-friction-and-wear tester (Fig. 8). The loading sequence and rotational speed are tailored to replicate the actual operating conditions of a gear-pump journal bearing. During the running-in phase, the bearing reaches a linear velocity of 2.5 m/s; accordingly, the same velocity is imposed on the test specimens. Running-in commence at 1 308 N for 5 min, after which the load is increased by 1 308 N every 10 min. Alarm limits are set at a specimen surface temperature of 180 °C and a frictional torque of 5 N·m. The counterface consisted of AISI 1045 steel, hardened to 40–45 HRC and finished to $R_a = 0.4 \mu\text{m}$.



Figure 8 HDM-20 face-friction-and-wear tester

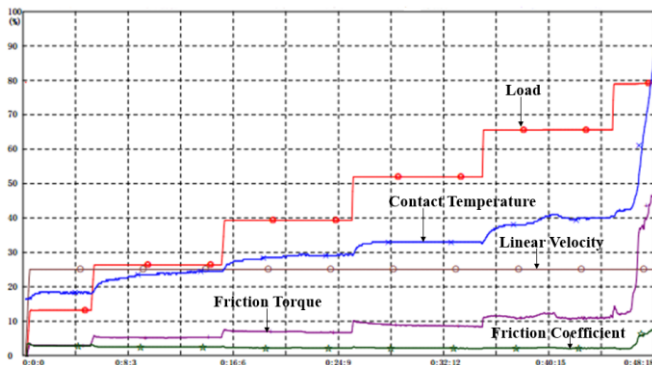


Figure 9 Bench Test Results of the PTFE Bearing

Figure 9 presents the experimental record for a journal bearing whose inner surface is coated with PTFE. The test is terminated 48 min after initiation when the frictional torque at the contact interface reached 5 N·m, triggering the test-rig alarm and marking the failure of the tribo-pair. A total of six load increments are applied, culminating in a final load of 7848 N. The terminal friction coefficient is 0.038, and the maximum contact temperature recorded at the tribo-pair was 180 °C.

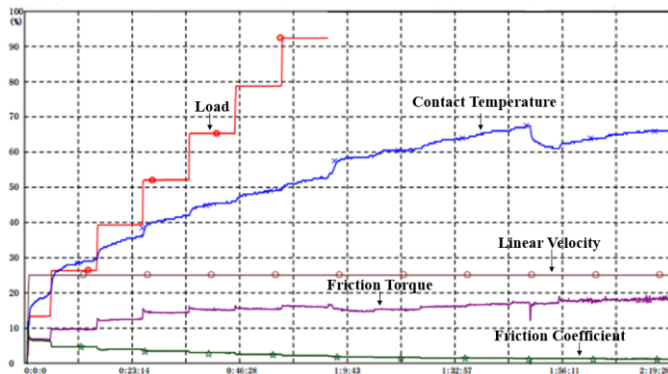


Figure 10 Bench Test Results of the PEEK Bearing

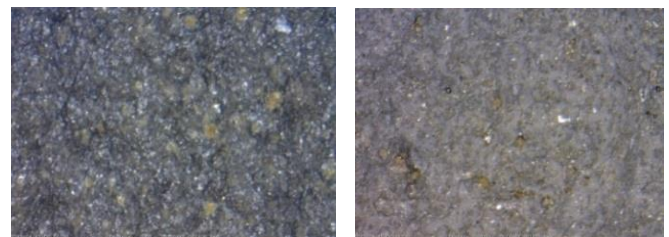
Figure 10 presents the bench-test results for a journal bearing whose inner surface is coated with PEEK. The experiment is halted after 2 h 7 min due to contact-surface failure. Throughout the test, seven load increments are applied, reaching a final load of 9156 N. The terminal friction coefficient was 0.007. The maximum contact temperature at

the tribo-pair was 132 ° C, and the peak frictional torque reached 1.9 N·m.

Comparative analysis reveals that, under high-speed conditions, the running-in duration of PEEK journal bearings is significantly longer than that of PTFE journal bearings. PEEK bearings also exhibit lower friction coefficients, shallower wear-scar depths, and lower peak contact temperatures. Consequently, the tribological performance of the PEEK coating surpasses that of the PTFE lining. It follows that PEEK journal bearings outperform their PTFE counterparts in overall performance.

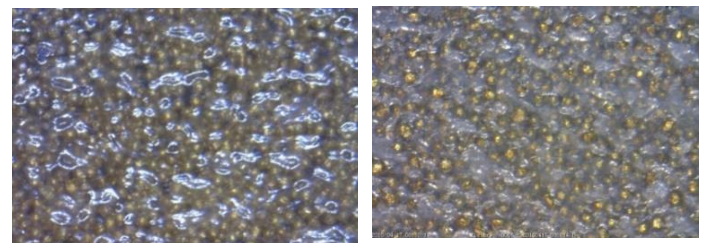
B. thermal stability test

The thermal stability test of the materials primarily assesses whether they maintain sufficient strength under elevated temperatures. Specimens of PEEK and PTFE were held at 250 °C for two hours, after which their surface microstructures were examined. Figure 11 shows the micrographs of PTFE at room temperature and after the 250 °C, 2-hour exposure, while Figure 12 presents the corresponding micrographs for PEEK.



(a) ambient temperature (b) maintained at 250 °C for 2 h

Figure 11 High-temperature test of PTFE material



(a) ambient temperature (b) maintained at 250 °C for 2 h

Figure 12 High-temperature test of PEEK material

As shown in Figures 11 and 12, after exposure at 250 °C the surface gloss of both materials decreases markedly; PTFE loses its gloss entirely, whereas PEEK retains a noticeable sheen. This observation indicates that PEEK possesses superior thermal resistance to PTFE. The PEEK composite exhibits a more uniform surface microstructure, which can endow wound bearings with enhanced service performance, including higher load-bearing capacity, better heat resistance, and elevated PV values. In summary, PEEK clearly outperforms PTFE in overall performance.

C. Bench-test validation

The plain bearing is manufactured with a PEEK inner-surface coating. The production process comprised the following

steps: sphere-powder-plate preparation, plate forming, blank cutting, small-blank blanking and marking, burr removal, copper-powder cleaning, curling, shaping, chamfering, oil-groove milling, finishing, polishing, cleaning, and packaging. The finished bearing is then assembled into a complete gear pump for durability testing. The bench test is conducted under an overload pressure of 23 MPa and a rotational speed of 2 000 r /min. The resulting volumetric efficiency versus time curve for the gear pump is presented in Figure 13.

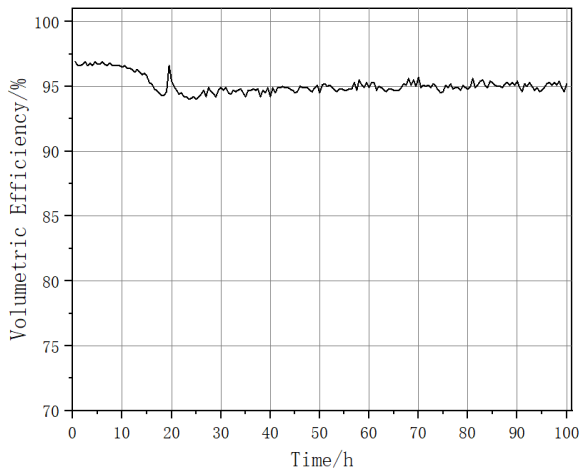


Figure 13 Volumetric Efficiency Curve of the Gear Pump with PEEK Journal Bearings

As shown in Figure 13, the durability test using PEEK-lined bearings reveals that during the first 30 h the volumetric efficiency fluctuates because all newly assembled pump components are undergoing break-in. From 30 h to 100 h the volumetric efficiency stabilizes at 95 % and shows no noticeable decline, indicating that all internal tribo-pairs are operating in good condition. After 100 h of running-in, the pump was disassembled; Figure 14 presents the appearance of the gear shaft and Figure 15 that of the journal bearing.

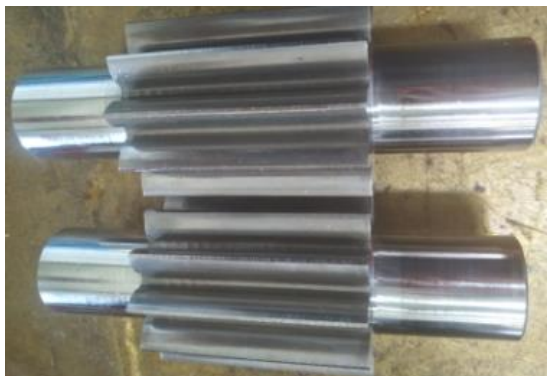


Figure 14 Gear shaft of the PEEK-bearing gear pump after 100 h running-in

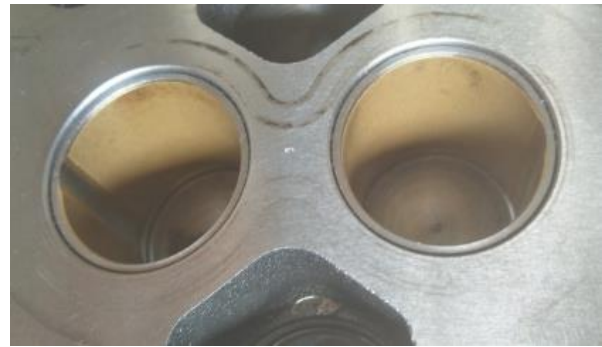


Figure 15 PEEK-lined plain bearing of the gear pump after 100 h running-in

Figure 14 shows that the contact zones between both ends of the gear shaft and the PEEK journal bearings exhibit no discoloration, and the shaft itself is free of any failure signs. Figure 15 reveals that after 100 h of running-in the PEEK bearings likewise display no pitting, blackening, or other modes of failure. Collectively, these results demonstrate that the gear pump equipped with PEEK journal bearings outperforms its PTFE-lined counterpart in terms of both volumetric efficiency and the surface integrity of the gear shaft and bearings.

IV. DISCUSSIONS

The present investigation confirms that the premature failure of gear-pump sliding bearings originates from an insufficient load-carrying capacity under severe duty cycles. The substitution of the conventional polytetrafluoroethylene (PTFE) liner with a polyether-ether-ketone (PEEK) coating emerges as a robust countermeasure, and the converging evidence obtained from three complementary experimental routes underscores both the validity of the root-cause diagnosis and the effectiveness of the proposed material upgrade.

Pin-on-disc tests show that the steady-state friction coefficient of PEEK coatings is about one-fifth lower than that of PTFE, the frictional torque is reduced by 2.5-fold, and the peak contact temperature drops by 48 °C. Additionally, the load-bearing duration of PEEK coatings is 2.6 times longer than that of PTFE, while the allowable axial load increases by 17 %. These improvements are ascribed to the higher compressive yield strength and superior creep resistance of PEEK, which preserve a conformal, low-shear interface even when the hydrodynamic film is momentarily disrupted under overload spikes. The lower frictional heating directly suppresses local thermal softening, thereby mitigating the positive feedback loop between temperature rise and bearing seizure that typifies PTFE-lined bearings.

After 100 h of isothermal exposure at 200 °C, morphological inspection reveals that PEEK retains its original crystalline structure and surface integrity, while PTFE shows a noticeable loss of gloss. The higher glass-transition temperature of PEEK and the absence of a first-order crystalline transition within the operating range jointly confer superior thermal stability. Consequently, PEEK-lined bearings can endure transient overloads and elevated

operating temperatures without undergoing the surface damage observed in PTFE bearings.

Overload bench tests demonstrate that pumps equipped with PEEK bearings maintain a 5–6 % higher volumetric efficiency throughout a 100-hour run-in period, while wear on both gear shafts and bearing bores remains within acceptable limits. In contrast, pumps fitted with PTFE sliding bearings show progressive volumetric efficiency decay, accompanied by severe wear on shafts and bushings that ultimately leads to film collapse and seizure. The doubling of run-in life with PEEK bearings is thus directly attributable to reduced friction, enhanced thermal robustness, and superior wear resistance.

Collectively, the experimental evidence confirms that inadequate bearing capacity—rather than deficiencies in gears or lubricant—constitutes the primary failure driver. The PEEK-based design modification simultaneously lowers frictional losses, widens the permissible temperature envelope, and suppresses wear progression, thereby delivering a tangible extension of pump service life. From a practical standpoint, the findings provide engineers with a validated material-substitution strategy that can be integrated into existing production lines with minimal geometric redesign, offering a cost-effective route to enhance the reliability and duty-cycle performance of high-pressure gear pumps.

V. CONCLUSIONS

To address the insufficient service life of the journal bearings in a bidirectional gear pump, PEEK is selected as the inner-surface coating material. Comparative tribological and durability tests were conducted, leading to the following conclusions:

(1)Endurance testing and post-test teardown analysis demonstrate that the efficiency decay and seizure observed in the bidirectional gear pump after 50 h of run-in are attributable to insufficient load-carrying capacity of the PTFE-coated sliding bearings, rather than to deficiencies in gears or lubricant.

(2)Comparative tribological and thermal-stability tests reveal that the PEEK coating significantly outperforms PTFE in terms of steady-state friction coefficient, wear-scar depth, peak contact temperature, and thermal resistance, providing a solid materials-science basis for enhanced bearing capacity.

(3)After retrofitting the pump with PEEK-coated bearings, the 100 h endurance test shows no measurable loss in volumetric efficiency; subsequent inspection confirms that the bearings and other rubbing components remain intact, effectively doubling the run-in life relative to the original design.

(4)The PEEK spray-coating technology can directly replace PTFE without altering the existing bearing geometry, offering an economical, rapidly deployable route to improve the reliability and service life of high-pressure gear pumps.

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