

# Analysis of The Causes of Premature Wear of Sealing Elements in Wankel Engines Under High Loads

**Illia Porokhnavets**

Owner, Restoration of classic Japanese and European cars.

Received: 28 January 2026 | Received Revised Version: 23 February 2026 | Accepted: 22 March 2026 | Published: 08 April 2026

Volume 08 Issue 04 2026 | Crossref DOI: 10.37547/tajet/Volume08Issue04-05

## Abstract

*The article examines the ensemble of causes of premature wear of sealing elements in the Wankel engine under high-load operating regimes from the standpoint of the coupled evolution of sealing performance, thermal state, and tribological contact conditions. The aim of the study is to formalize the causal cascade of pressure, heat release, deformation, lubrication, and wear, and to interpret premature failure as the assembly's exit from its functional window rather than as a simple acceleration of material loss. The relevance of the work stems from the growing interest in highly loaded rotary power plants, where seal durability remains a key limitation to reliability and efficiency. Based on a synthesis of contemporary computational and experimental data on leakage dynamics, coating contact fatigue, and lubrication regimes, an integrated degradation framework is proposed that links local overheating, vibrational mobility of seals, and the transformation of wear mechanisms from abrasive and adhesive to fatigue and corrosion–chemical. The scientific novelty lies in the systematic description of failure scenarios for apex, side, and corner seals under load as self-sustaining loops, as well as in the emphasis on diagnostic indicators and engineering strategies for breaking the cascade through control of the thermal regime, lubrication, detonation, and the selection of tribological pairs. The article is intended for designers and researchers of rotary engines, tribology specialists, engine manufacturers, and operating engineers dealing with highly loaded units.*

Keywords: Wankel engine, apex seals, premature wear, high loads, tribology

© 2026 Illia Porokhnavets. This work is licensed under a Creative Commons Attribution 4.0 International License (CC BY 4.0). The authors retain copyright and allow others to share, adapt, or redistribute the work with proper attribution.

**Cite This Article:** Porokhnavets, I. (2026). Analysis of The Causes of Premature Wear of Sealing Elements in Wankel Engines Under High Loads. *The American Journal of Engineering and Technology*, 8(4), 61–69. <https://doi.org/10.37547/tajet/Volume08Issue04-05>

## Introduction

The durability of sealing elements in Wankel engines remains the determining constraint for long-term operation in high-power modes, since in the seal–housing contact zone, sealing, heat removal, and friction control are simultaneously integrated into a single system. Modern reviews on

apex seals emphasize that wear, gas leakage, and vibrational phenomena form an interconnected triangle of problems: leakage intensifies local overheating, overheating degrades the lubrication regime, and vibrations and oscillations of the seal increase impact loading and accelerate edge destruction, especially as combustion-chamber pressure rises (Ji et al., 2022). Within the framework

of this article, it is important to proceed from the fact that under high loads several physically distinct causes of degradation are simultaneously amplified in the Wankel engine; consequently, the analysis must rely not on a single indicator but on an entire chain of causal transitions: from the thermal and stress state of the assembly to the friction regime and further to a specific wear mechanism.

In the context of seals, premature wear is more correctly understood not as an abstract rapid aging but as a measurable displacement of the assembly beyond its operable window: an increase in leakage and loss of compression, the emergence of persistent traces of non-uniform contact, loss of seal mobility in the groove, or accelerated growth of damage to the working edge leading to failure before the expected life under comparable operating conditions. This formulation is convenient for scientific analysis because it links wear not only to the magnitude of material removal but also to the sealing function and seal dynamics: when a seal begins to live in the groove as an oscillatory system, the probability of separation, impacts, and local overheating increases, and leakage and wear start to reinforce each other. Models focused on the pressure beneath the seal and on the dynamic component of leakage show that even small changes in the conditions of preload and oscillation can significantly alter the magnitude of losses through the apex-seal region, that is, can shift the assembly into a different operating regime before the total wear has become visually pronounced (He et al., 2025).

The operation of Wankel seals differs from that of piston-engine rings not only in trajectory geometry but also in the nature of contact: instead of a relatively extended ring-cylinder interface, the dominant feature is a localized, highly loaded contact between the apex seal and the housing, which is sensitive to misalignment, edge effects, and thermally induced deformations. This renders the lubrication regime more fragile: with changes in temperature, pressure, and sliding speed, the contact readily transitions to mixed and boundary lubrication, where the probability of scuffing and

fatigue failure rises sharply, and small geometric deviations produce a disproportionately large effect. For this reason, contemporary tribological studies of the apex seal-housing interface emphasize elastohydrodynamics and design measures aimed at reducing edge-stress concentration and stabilizing the oil film during thermal deformation, which is typically less pronounced in piston rings (Li & Chen, 2025).

### Materials and Methodology

The material basis of the study is a coherent body of works that describe premature wear of Wankel seals under high loads through the interrelation of sealing, heat transfer, and friction. As reference sources, recent review and modeling publications on apex seals and leakage dynamics are used, in which wear is treated as an effect of coupled degradation leakage-overheating-vibration, and it is demonstrated that small variations in preload and oscillatory behavior can shift the assembly into another operating regime even before large cumulative wear appears (Ji et al., 2022; Üner & Cihan, 2025). For tribological substantiation of transitions to unfavorable lubrication regimes, studies are employed that link boundary/mixed lubrication to the loss of film load-carrying capacity as temperature and pressure increase, as well as investigations of elastohydrodynamics with structural thermal coupling as the mechanism by which deformations and temperature gradients redefine contact stresses and minimum film thickness (Stephan et al., 2023; Li & Chen, 2025).

The methodology is constructed as a causal analysis in which premature wear is defined not as accelerated aging but as the exit of seals from their operable window according to functional metrics: an increase in leakage and a drop in compression, the emergence of persistent non-uniform contact, loss of mobility in the groove, and accelerated edge damage. Within this framework, high loads are considered a multifactor operating regime that compresses the stability margin of the contact: elevated pressure increases preload and contact stresses, higher sliding speed intensifies heat

generation, and thermally induced deformations shift the contact line and provoke edge overload, thereby driving lubrication toward mixed and boundary regimes and initiating a cascade of adhesive, abrasive, and fatigue mechanisms.

To verify the logic of the cascade, comparisons are made with studies on contact fatigue of coatings and on the selection of seal–housing tribological pairs, where life is associated with resistance to scuffing and spalling under cyclic stress peaks, as well as with works demonstrating the importance of coupled thermo–hydro–mechanical modeling of seal wear at high speeds and loads (Wang et al., 2023; Gupta et al., 2020; Wei et al., 2024).

## Results and Discussion

The sealing system of the Wankel engine is organized as a combination of radial and end barriers to leakage, with each element operating in its own, sometimes conflicting, mechanical and thermal regime. Apex seals, located at the rotor vertices, separate the working chambers and simultaneously experience the most severe combination of factors: high specific contact pressure, variable sliding speed along the epitrochoid housing surface, and intense heat flux from the combustion zone. Their preload against the housing is determined by elastic elements and the gas pressure beneath the seal; sealing performance becomes a dynamic quantity: pressure oscillations and microdisplacements in the groove change the real contact area and the conditions for lubrication film formation. In computational and experimentally confirmed approaches, this is described as a finite-length contact with pronounced edge effects, in which the housing's profile geometry directly governs the minimum film thickness and, consequently, the onset of unfavorable friction regimes (Üner & Cihan, 2025).

Side and corner seals close the end sealing paths and join leakage circuits that the apex seal alone cannot block, so their role cannot be considered secondary. Side seals form a barrier between the working chamber and the side plates, while corner seals close the transition region apex–side, where

geometry becomes more complex and sensitivity to clearances and contamination increases. Under high loads, these interfaces often become the main leakage paths, and leakage, in turn, intensifies local overheating and accelerates wear of the contact edges. For this reason, modern leakage models distinguish the geometric component from the dynamic component associated with vibrations and seal mobility in the groove (Ji et al., 2022). In practical terms, this means that sealing degradation in the Wankel engine is rarely localized: deterioration of one element rapidly redistributes loading onto adjacent elements, alters the temperature field, and shifts wear maxima to other regions.

Lubrication supply under such conditions is inevitably composite. A portion of the oil is fed into the intake tract or directly into the working chamber by a metering system; another portion is transported as mist and film along surfaces and is then entrained into the seal–housing contact and into end clearances. Oil-control elements and oil channels must simultaneously maintain a film thick enough to reduce friction and prevent uncontrolled oil burning. Otherwise, deposits and the risk of seals sticking in the grooves increase. From this, stringent requirements for materials and coatings naturally follow: they must retain scuffing resistance at high temperatures, withstand cyclic loading without spalling, and remain compatible with the lubricant and combustion products. Studies on coatings for rotary-engine components discuss aluminosilicon-based compositions and nickel–chromium–chromium carbide systems, with the key criteria being contact fatigue and the ability to remain functional in the seal–lubricant–surface system at elevated pressures (Wang et al., 2023). Additional emphasis is placed on selecting seal–housing coating pairs that suppress characteristic surface vibrational wear patterns and reduce the coefficient of friction under insufficient lubrication (Gupta et al., 2020).

From a tribological perspective, the seal contact is not locked into a single regime. At favorable temperatures and with sufficient oil supply, a

hydrodynamic film may exist, but as load and temperature increase, a mixed lubrication state typically develops, and in local regions—especially at edges and under housing deformation—boundary friction arises (Stephan et al., 2023). These transitions hide the fundamental mechanisms of premature wear: abrasive wear is triggered by hard particles of dust, deposits, and fragments of coating wear; adhesive wear manifests as seizure and scuffing upon film rupture; fatigue wear develops through microcracking and spalling under repetitive pressure peaks; the corrosion–chemical component is amplified by surface reactions with combustion products and oxidation during overheating, which impair film retention and facilitate destruction of the surface layer. Taken together, this forms a characteristic self-reinforcing pattern for the Wankel engine: deterioration of lubrication raises friction, friction increases temperature, temperature accelerates deposit formation and oxidation, and seal dynamics increase the impact character of contact, thus preparing the ground for accelerated degradation, which is then expedient to analyze through specific high-load factors (Feng & Shao, 2025).

Under high loads, seal wear is accelerated primarily by increased gas pressure in the combustion chamber, which increases the preload on the sealing edges against the housing surface. This preload benefits sealing, but it also elevates contact stresses to a level at which any defect in lubrication or geometry instantly transforms into a local overload. A bottleneck effect arises: the contact zone is small while the energy flux through it is large, so the system loses stability margin and begins to respond to small perturbations with abrupt increases in friction and temperature.

Simultaneously with rising pressure, the relative sliding speed in the most heavily loaded regions of the trajectory increases, and with it the rate of heat generation in the contact (Wei et al., 2024). Crucially, heat is not produced uniformly across the surface but is concentrated where contact becomes edge-dominated and the film thins. Under these conditions, even modest roughness or waviness

leads to alternating sticking and slipping, sharply increasing the risk of scuffing and accelerating fatigue failure of the edges. The result is not merely more friction but a change in the interaction regime itself, where the contact begins to act as a source of impulsive loads.

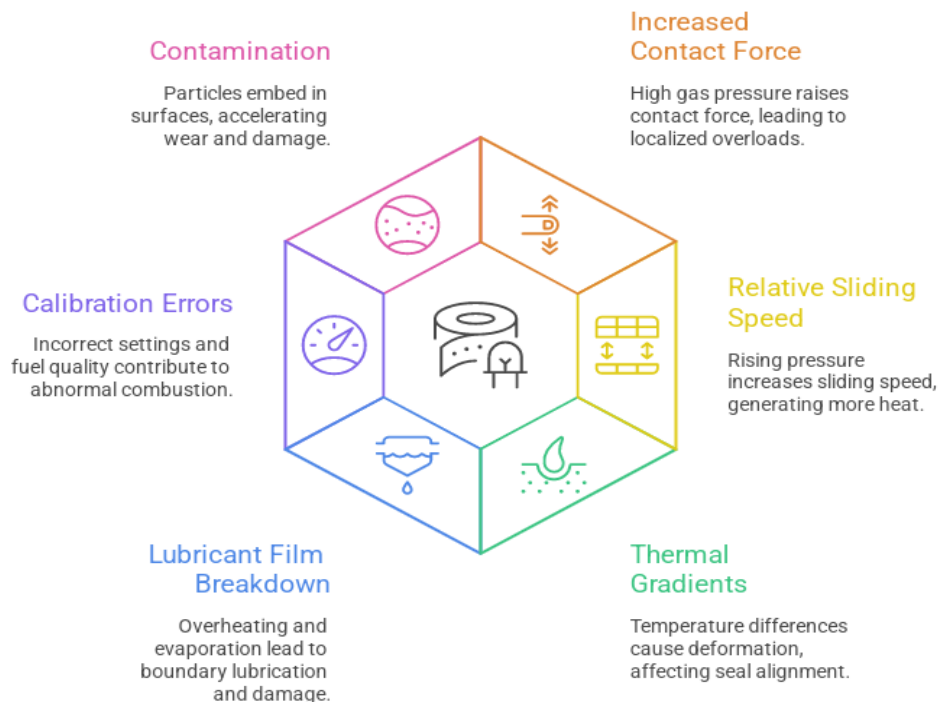
Non-circularity, torsion, and thermal gradients cause increased housing and rotor deformations, which shift the contact line and the total clearance to discrete segments (Wei et al., 2024). The seals must be able to float in their grooves and compensate for the geometrical deformations, which complicates the design. When, therefore, the seals lose this ability, the seal operates misaligned, its edge is inhomogeneously loaded, and leaks locally, causing a thermal spike where the contact is especially compromised by overheating. In this way, the degradation loop forms: deformation leads to leakage, leakage leads to a thermal spike, and the thermal spike leads to the consolidation of the deformation and the degradation of lubrication.

The central mechanism responsible for the transition to boundary friction is the breakdown of the lubrication film due to overheating and oil evaporation. At high temperatures, viscosity decreases, the film's load capacity is reduced, and the probability of film rupture in regions of maximum shear increases. If detonation or pre-ignition is superimposed, the contact is subjected to shock pressure waves that act as short-duration overloads: they strip the film, cause micro-chipping, and promote surface spalling, after which abrasive particles from the damage products accelerate wear (Wei et al., 2024). Against this background, deposit formation ceases to be merely a secondary effect and becomes a structural factor: coke in the groove's limits seal stroke, disrupts preload, and turns a mobile element into a jammed wedge that either allows gases to pass or overloads the edge.

A separate contribution arises from calibration errors and fuel quality, because these directly define the thermal and impact characteristics of the combustion process. An overly lean mixture,

incorrect ignition timing, excessive load under insufficient cooling, and unstable fuel composition increase the likelihood of abnormal combustion and overheating, thereby accelerating all chains that lead to seal destruction. Contamination and poor air filtration amplify the abrasive component: hard particles embed in the surface, disrupt film formation, and hasten the loss of sealing, with the

effect especially sharp at high pressures, where each particle acts as a stress concentrator. Ultimately, premature wear under load should be regarded as the result of a simultaneous shift of mechanical, thermal, and tribological balances into a domain where small disturbances evolve into self-sustaining damage. Seal Failure Mechanisms are shown in Figure 1.



**Fig. 1.** Seal Failure Mechanisms

Under high-load conditions, seal failure most often occurs in a cascade, in which the initial event may not appear critical but alters the contact regime, making subsequent damage inevitable. The most common pathway begins with overheating: temperature in the contact zone rises, oil viscosity decreases, the lubrication film thins, and then ruptures. The contact transitions to boundary friction, seizure occurs, and scuffing forms on the housing surface and on the working edges of the apex seals. Once a longitudinal wear track forms, it becomes a guide to further destruction, as the seal is forced to traverse an already damaged path under an even more unfavorable pressure distribution.

Failure initiated by detonation has a different character: here, the key factor is not gradual

lubrication degradation but shock overloading. Short-duration contact stresses and temperatures induced by pressure waves cause microchipping of the seal edge and spalling of the housing coating. Even episodic detonation causes damage, leading to accelerated mechanical seal wear by disrupting the lubricating film's continuity and creating hard particles that increase the abrasive component of wear. Thus, the material's degradation becomes a self-propagating process, with surface damage serving as the basis for subsequent detonation damage and increasing the size of the defect.

The scenario associated with coke deposits often develops covertly and is therefore particularly dangerous during prolonged operation under load. Deposits in the grooves limit seal mobility and

compromise its ability to follow micro-deformations of the housing. The seal either sticks to the edge (allowing gas blow-by at the recess) or lifts out of the recess and over the edge (overloading it and causing local overheating). Hot gas blow-by increases oxidation and deposits, while local overheating increases oil degradation. As a result, the failure mode is not a sudden event, but a slow degradation of normal mobility and thermal balance.

The abrasive scenario begins with the ingress of hard particles or the formation of hard wear products and oil combustion products, after which accelerated material loss becomes dominant. The

particles act as micro-tools, disrupting the lubrication film and sawing through the surface, reducing sealing and compression. At high rotational speeds, another mechanism is added: seal oscillations, in which the contact ceases to be continuous and becomes impact-like. The seal partially lifts off, then returns and delivers a series of micro-impacts to the housing surface. Such dynamics sharply accelerate fatigue damage and explain why, at the same average load, high-speed regimes with abrupt transitions are more likely to cause chipping and spalling than uniform wear. Seal Failure Pathways Under High Load are illustrated in Figure 2.



Fig. 2. Seal Failure Pathways Under High Load

Diagnosis of premature seal wear must begin from observable operational symptoms, because these reflect loss of functionality rather than merely the presence of wear. Loss of compression manifests as degraded starting performance, especially on a hot engine, unstable idling, and reduced thrust in transient modes when rapid chamber pressure changes are required. Increased oil consumption and exhaust smoke are key factors. They indicate an unstable lubrication balance: insufficient oil results

in dry contact rather than a hydrodynamic film, or oil burning off more quickly, which causes rapid deposit buildup and an increased risk of sealing surfaces sticking together. Symptoms should be assessed in the context of an engine's operating regime. If high load has been sustained for too long, thermal degradation and/or gas blow-by at a damaged edge is more likely.

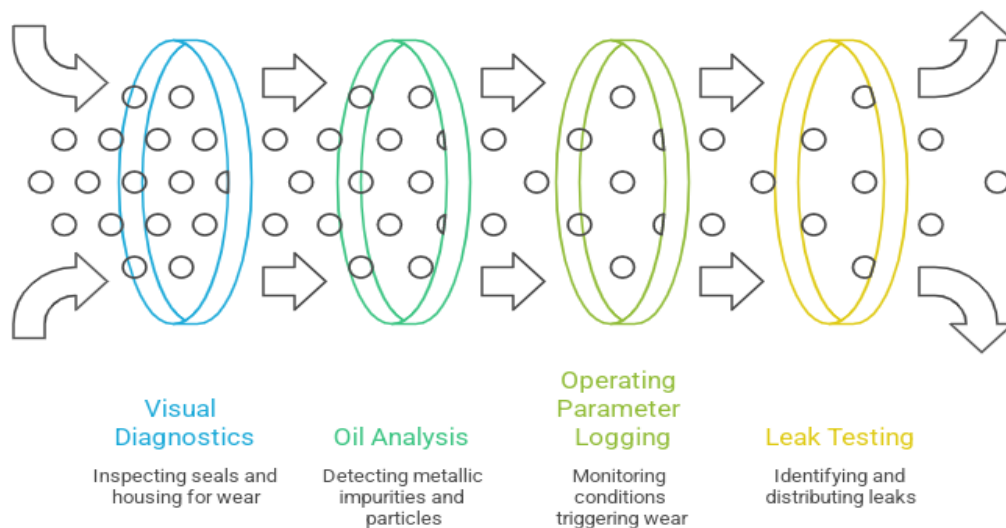
Visual diagnosis by endoscopy enables the transition from symptoms to a hypothesis regarding

the mechanism. In the housing, characteristic polishing tracks, scratches, and scuffing along the apex-seal path are observed; their geometry and location indicate whether the cause lay in overheating and film rupture, abrasive action, or impact-dominated operation. On the seals themselves, informative features include edge chipping, spalling, signs of overheating and discoloration, as well as indications of sticking in the grooves, when the contact surface appears unevenly over-compressed or, conversely, underworked. Particular attention must be paid to the interface between side and corner seals, since a hidden leakage path often forms there, later leading to local overheating and accelerated wear.

Oil analysis is useful for identifying problems before they become obvious in compression measurements. Increased metal content and the presence of hard particles indicate active wear of the tribological pair and coating failure, while changes in contamination patterns allow distinguishing gradual abrasive degradation from episodic impact damage, after which larger fragments enter the oil. This approach is especially valuable for engines operating under high load,

where wear develops rapidly and in phases: a short period of relatively stable operation may be followed by abrupt deterioration after the contact transitions to the boundary regime.

Logging of operating parameters links diagnosis to the cause and helps separate effects from the problem's origin. Monitoring mixture composition, exhaust temperature, intake air temperature, and detonation indicators enable identification of the conditions under which overheating, shock loading, and coke-forming scenarios are triggered. Diagnostic procedures should conclude with a sealing assessment using adapted leakage tests, because they reveal not only the fact of compression loss but also the distribution of leakage across chambers and phases, which is important for distinguishing apex-seal wear from leakage through end-sealing paths. Taken together, these methods provide a coherent picture: symptoms indicate a functional shift, visual evidence clarifies the mechanism, oil records the dynamics of damage, and operating parameters explain why degradation began specifically under load. Diagnosing Premature Seal Wear is shown in Figure 3.



**Fig. 3.** Diagnosing Premature Seal Wear

To prevent early seal wear in high-load service, it is necessary to break the chain of causative events that leads from film overheating to inadequate lubrication, followed by film breakdown and

overheating with scuffing. This is mostly a matter of temperature control: maximizing the heat carried away from the housing and side plates, avoiding local hot spots, and monitoring the exhaust

temperature as a warning that combustion was getting excessive. Thermal control is not reduced to temperature reduction; it must ensure stability of the temperature field, since gradients cause deformations that shift the contact line and provoke edge overload on the seals. The second key measure is stabilization of lubrication: oil metering must guarantee film formation in the most vulnerable segments of the trajectory, while oil selection and change intervals must be subordinated to thermal stability and resistance to deposit formation; otherwise, the lubricant becomes a source of coke products that block seal mobility in the grooves.

Protection against detonation is necessary to eliminate shock overloads that instantaneously create microchips and initiate spalling of the housing coating. This is achieved by coordinating mixture and ignition settings with the engine's actual thermal state, using fuel with sufficient knock resistance, and lowering intake-air temperature through efficient charge-air cooling, so that the combustion process remains predictable during sustained high-load operation. On the design level, life is extended by selecting seal materials and housing coatings with high resistance to scuffing and contact fatigue and by specifying a surface roughness that retains the film without becoming a source of abrasive wear. Here, the decisive factor is not maximum smoothness but an appropriate surface texture. Finally, strict control of assembly and clearances is required to ensure seal mobility and correct preload without misalignment, as well as to prevent contamination through efficient air filtration and the elimination of unmetered air entry, since abrasive particles under high pressure act as accelerators in any failure scenario.

### Conclusion

Premature wear of sealing elements in Wankel engines under high loads should be interpreted as the exit of the assembly from its functional window, in which sealing, heat removal, and friction management cease to support each other coherently and instead form mutually reinforcing degradation. In this regime, the decisive factor is not a single

symptom of wear but a chain of transitions: increasing pressure and heat flux alter the mechanical and thermal state of the contact, then shift the lubrication regime from hydrodynamic to mixed and boundary, and only then does a specific damage mechanism become evident—from scuffing and adhesive seizure to fatigue spalling and abrasive material loss. It is noteworthy that even small changes in preload and the seal's oscillatory mobility in the groove can shift leakage and contact into another regime before large cumulative wear develops, confirming the dynamic nature of sealing in the Wankel engine.

The causal relationships identified in the discussion show that under load, the key accelerator of wear is the compression of the contact's stability margin: elevated gas pressure enhances edge preload and raises contact stresses, while increased sliding speed and heat generation concentrate overheating in edge regions where the film thins first. Temperature gradients deform the housing and rotor, shifting the contact line and clearances. Poorly mobile seals prevent full geometric compensation, leading to a closed geometric system of deformation, leakage, thermal shock, and lubrication failures. In this case, the impulsive nature of the detonation results in short-lived pressure spikes impinging on the film, stripping it off to produce micro-chips, and coke deposits preventing stroke in the groove. The adaptive element thus behaves like a wedge that either allows the gases to pass or overstresses the edge, causing superheating and surface failure.

Consequently, scientifically grounded preventive measures must target the failure cascade itself rather than its late manifestations. Thermal management must be understood as the stabilization of the temperature field and the suppression of gradients, since these trigger deformation-induced contact shifts; lubrication stabilization must be understood as the guarantee of film formation in the most vulnerable trajectory segments, combined with control of deposit formation, otherwise the lubricant becomes a source of jamming. Complementary measures in the form of detonation protection,

mixture and ignition control, air filtration, correct clearances and seal mobility, and the selection of seal–housing coating tribological pairs resistant to scuffing and contact fatigue complete the proposed picture: under high loads, life is determined by whether the tribological regime can be kept from collapse and small disturbances can be prevented from evolving into self-sustaining damage.

#### References

1. Feng, K., & Shao, T. (2025). Oxidation Dominated High-Temperature Friction and Wear Behavior of Composite Coating NiCr-Cr<sub>3</sub>C<sub>2</sub>-BaF<sub>2</sub>/CaF<sub>2</sub>. *Journal of Thermal Spray Technology*, 34(5), 1813–1830. <https://doi.org/10.1007/s11666-025-01984-8>
2. Gupta, A., Jayaram, S., & McCormick, H. E. (2020). Identification of materials and coatings to minimise/eliminate Wankel rotary engine's apex seal/trochoid wear chatter. *International Journal of Surface Science and Engineering*, 14(2), 135. <https://doi.org/10.1504/ijsurfse.2020.108224>
3. He, L., Xu, G., Li, M., & Huang, X. (2025). Leakage mechanism and dynamic response characteristics of double-seal O-ring structures in nuclear power engineering. *Nuclear Engineering and Design*, 442, 114239. <https://doi.org/10.1016/j.nucengdes.2025.114239>
4. Ji, C., Yang, Z., Yang, J., & Wang, S. (2022). Research overview of rotary engine apex seals. *Chinese Journal of Engineering*, 44(8), 1406–1424. <https://doi.org/10.13374/j.issn2095-9389.2021.06.02.002>
5. Li, J., & Chen, G. (2025). Modeling and experimental study of reciprocating seal Soft elastohydrodynamic lubrication considering structural thermal coupling. *International Journal of Heat and Mass Transfer*, 239, 126564. <https://doi.org/10.1016/j.ijheatmasstransfer.2024.126564>
6. Stephan, S., Schmitt, S., Hasse, H., & Urbassek, H. M. (2023). Molecular dynamics simulation of the Stribeck curve: Boundary lubrication, mixed lubrication, and hydrodynamic lubrication on the atomistic level. *Friction*, 11(12), 2342–2366. <https://doi.org/10.1007/s40544-023-0745-y>
7. Üner, E., & Cihan, Ö. (2025). Analysis of Apex Seal Dynamic Behavior in a Wankel Engine. *International Journal of Automotive Science and Technology*, 9(2), 186–193. <https://doi.org/10.30939/ijastech..1637285>
8. Wang, K., He, G., Chai, Y., & Wang, L. (2023). Contact fatigue properties of NiCrCr<sub>3</sub>C<sub>2</sub> and AlSi coatings for sealing performance of the Wankel engine. *International Journal of Fatigue*, 172, 107655. <https://doi.org/10.1016/j.ijfatigue.2023.107655>
9. Wei, J., Xue, Y., Tian, J., & Guo, F. (2024). Study on the prediction of high-speed rotary lip seal wear in aero-engine based on heat-fluid-solid coupling. *Industrial Lubrication and Tribology*, 76(2), 167–177. <https://doi.org/10.1108/ilt-10-2023-0320>