Advances in Science and Technology Research Journal

Advances in Science and Technology Research Journal, 2026, 20(6), 557–571
https://doi.org/10.12913/22998624/219054
ISSN 2299-8624, License CC-BY 4.0

Received: 2026.01.25
Accepted: 2026.04.15
Published: 2026.05.01

Current situation and prospect of design, manufacturing and inspection technology of gear transmission for new energy vehicles

Xuezhong Fu[1,2], Zhongwei Zeng[1], Lin Lu[3*], Wei Ruan[4], Shuping Li[1]

[1] School of Mechanical and Automotive Engineering, Guangxi University of Science and Technology, No. 19 Guantang Avenue, Yufeng District, Liuzhou 545006, Guangxi Zhuang Autonomous Region, China
[2] Guangxi Critical Laboratory of Auto Parts and Vehicle Technology, Liuzhou 545006, China
[3] School of Automation, Guangxi University of Science and Technology, No. 19 Guantang Avenue, Yufeng District, Liuzhou 545006, Guangxi Zhuang Autonomous Region, China
[4] Parts Research Institute, Guangxi Liugong Yuanxiang Technology Co., Ltd., No. 2 Liugong Avenue, Hexi Sub District, Liuzhou 545006, Guangxi Zhuang Autonomous Region, China
* Corresponding author's e-mail: 100002364@gxust.edu.cn

ABSTRACT

With the rapid development of new energy vehicles, gear transmission systems are facing increasingly stringent demands for high efficiency, low noise, high reliability, and performance under high-torque variable-load conditions. The design, manufacturing, and inspection technologies of gears are crucial to the reliability and safety of new energy vehicles. Firstly, this paper summarizes the influence of tooth flank modification on NVH (noise, vibration and harshness) in gear transmission design for new energy vehicles. Secondly, the impact of grinding and power honing on gear manufacturing within the production technology of new energy vehicle gear transmissions is elaborated. Third, the application of optical inspection and deep learning in gear inspection technology for new energy vehicles is discussed. Finally, prospects for gear technology are provided, focusing on AI-driven design, multi-energy field hybrid manufacturing, and non-contact inspection technologies.

Keywords: new energy vehicles, gear transmission design, gear manufacturing, gear inspection.

INTRODUCTION

Gear transmission is widely used in the transmission system of new energy vehicles because of its high efficiency, accurate transmission, compact structure, reliable operation, long service life, wide power range, simple maintenance, and many other advantages. Compared with fuel vehicles, new energy vehicles simplify the clutch and torsional shock absorber, and mostly use the motor to directly couple with the reducer. Thus, the transmission system structure becomes extremely compact, and the input speed of the motor is high, which makes the vibration and noise of gear transmission more obvious (due to the loss of the masking effect of the engine). Therefore, the high-speed and low-noise gear has become the most ideal component of the gear transmission system of new energy vehicles, but it still encounters numerous challenges in practical service: it must not only meet strict performance indicators such as high precision and low noise [1-3], but also solve problems such as ghost howling at high speed [4], and meshing impact at regenerative braking [5]. This puts forward strict requirements on the design, manufacturing and inspection technology of gear transmission. Gear transmission design directly affects the key evaluation indexes such as power output, transmission efficiency and NVH of new energy vehicles. Reasonable design of gear transmission can optimize power transmission, ensure transmission accuracy and meet various complex transmission requirements. The manufacturing accuracy of gears plays a decisive role in transmission efficiency, noise control and service life. The gear employed in new energy vehicle transmission systems typically achieves accuracy grades of 4 to 6, which is higher than the grades of 7 to 8 commonly found in traditional internal combustion engine vehicle transmissions [6, 7]. Therefore, the high speed and low noise transmission demand of new energy vehicles promote the development of gear manufacturing technology towards higher manufacturing accuracy. In addition, gear inspection is an important link in the efficient and reliable operation of gear transmission, which directly affects the reliability of new energy vehicles. Through high-precision inspection technology, geometric errors can be effectively evaluated and controlled to ensure that it meets the design specifications.

Therefore, the important progress made in the research of gear transmission for new energy vehicles is summarized in this paper from three aspects: design, manufacturing, and inspection technology. The future development direction of gear transmission design, manufacturing and inspection technology for new energy vehicles is prospected, which provides a reference for the next stage of research.

DESIGN TECHNOLOGY OF GEAR TRANSMISSION FOR NEW ENERGY VEHICLES

Gear transmission design mainly includes tooth surface modification design and new tooth profile design [8, 9]. Tooth surface modification can reduce noise and improve bearing capacity by local optimization of tooth surface without changing the basic tooth profile (such as involute). The new tooth profile can significantly improve its many properties through the design of tooth profile, but its application scope is limited due to manufacturing technology and actual demand. The gear transmission design of new energy vehicles mainly adopts the customized modification schemes of involute gear, and the new tooth profile design is rarely used [10]. Typical steps of gear modification are shown in Figure 1.

Tooth surface modification (including tooth profile modification, tooth lead modification and topological modification) is one of the important means to improve NVH characteristics of the gear transmission system, and it is the simplest and most efficient way to reduce noise and vibration, which has an important impact on the comfort of new energy vehicles [11]. Baek et al. [12] effectively reduced the gear transmission error by tooth profile modification to reduce the noise of electric vehicles, and obtained the optimal design conditions considering noise and strength. Wang et al. [13] obtained the transmission error and spectral characteristics of the high-speed gear of the electric vehicle reducer by modifying the addendum and helix, which provided a valuable reference for analyzing the influence on the NVH performance of the electric vehicle reducer. Zhi et al. [14] took the minimum change of static transmission error of load as the objective function, and obtained the optimal tip trimming length of gear pair, which provided a reference for the design and optimization of gear transmission system of electric vehicle. The above research mainly focuses on the radial gear tooth modification of the gear tooth surface, that is, the tip or root area is slightly cut off to achieve the purpose of easing the meshing impact and improving the meshing smoothness. Tooth profile modification is a gear tooth modification along the tooth width direction, which is mainly to compensate the deflection or assembly error of the gear shaft. Common forms such as middle crowning, cone shape and local end modification. Wu [15] determined the tooth-to-drum modification parameters according to the transmission error, contact spots and vibration response of the case when the gear of the electric vehicle transmission was running, and verified the improvement of the NVH of the transmission by modification. Li et al. [16] analyzed the transmission error and contact spot in the electric vehicle reducer, and both performance indexes were effectively improved after tooth top modification. Topological modification is the combination of tooth profile and tooth direction modification to form complex modification. Zou [17] analyzed the order of the main noise in the hybrid transmission, and modified the tooth profile drum, tooth direction drum and helix angle. The modification effect was analyzed and further optimized in Romax. In order to reduce the vibration and noise of the differential gearbox of electric vehicles, Xiang et al. [18] proposed to modify the tooth ends of the drum tooth. Thus, the scheme of addendum modification of tooth profile is carried out.

In summary, while gear modification is an important means of reducing vibration and noise,

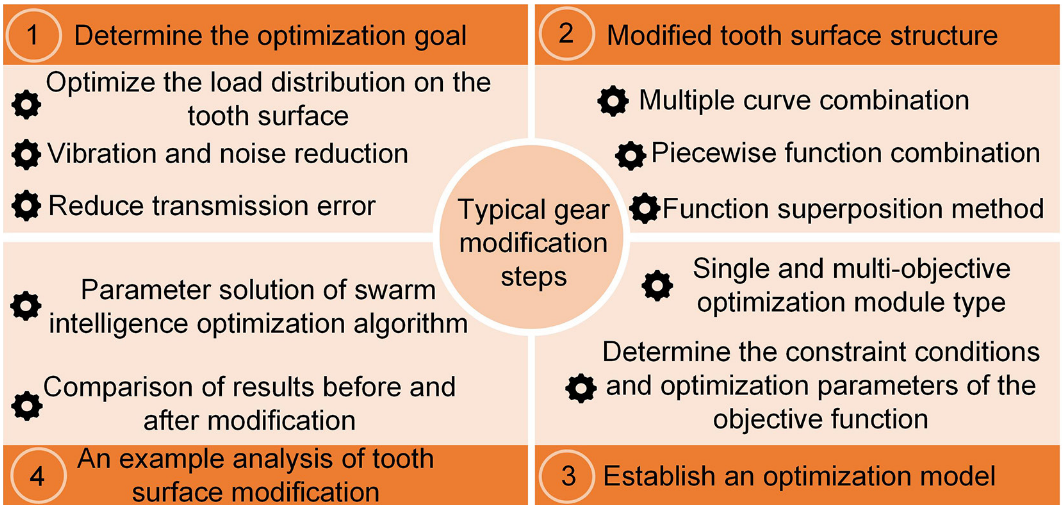

Figure 1. Typical steps of gear modification

its effectiveness is constrained by actual operating conditions such as load, rotational speed, and assembly errors. If the actual operating conditions deviate significantly from the design parameters, modification may even lead to a deterioration in gear meshing performance. Topological modification typically outperforms single-dimensional modification, primarily because it allows for more comprehensive compensation of meshing excitations caused by integrated factors such as load-induced deformation and assembly errors through the coordinated design of parameters. However, the determination of such modification parameters still relies heavily on empirical exploration, which limits its further development. Topological modification is not merely an adjustment of a single parameter; rather, it involves the combinatorial design of parameters such as crowning amount, helix angle modification, and tip relief along both the profile and lead directions, aiming to find the optimal solution based on the problem type (e.g., whining, uneven load distribution) and target performance (e.g., reducing transmission error, equalizing contact patterns). The research types, the modified parameter combinations employed, and the performance indicators of concern in several typical studies are summarized as shown in Table 1. Additionally, modification accuracy is often measured in micrometers, requiring high-precision computer numerical control (CNC) gear grinding, honing, or skiving equipment for implementation. In practice, achieving perfect consistency with the theoretical modification curve during actual machining remains challenging. Although academia has proposed numerous complex modification theories to optimize gear tooth surface geometry, in practical engineering applications, the final selection of a gear design scheme is often the result of a multi-objective trade-off. Besides pursuing theoretically optimal meshing performance, manufacturing economy is another key consideration. Compared to expensive tooth surface modifications, applying sound-absorbing/soundproofing coverings on the exterior of the gearbox may be more suitable. Furthermore, the viscosity grade of the lubricant directly determines the oil film thickness, which in turn affects the contact fatigue strength (pitting) and anti-scuffing capability of the gear surface. Therefore, choosing an appropriate lubricant can often achieve quite satisfactory results.

MANUFACTURING TECHNOLOGY OF GEAR TRANSMISSION FOR NEW ENERGY VEHICLES

New energy vehicles impose demands on high quality, precision, and reliability in gear processing to meet the needs of efficient transmission, low-noise operation, and lightweight construction [19]. Traditional machining methods such as gear hobbing, gear shaping, and gear shaving, though mature in technology and cost-effective, have certain advantages in mass production but are generally limited to manufacturing gears of medium-to-low precision, making it difficult to fully satisfy the stringent performance requirements for gears in new energy vehicles [20]. Grinding and power gear honing have become

Table 1. Research on tooth profile modification in gear design

Research type	Modification parameters	Problem types\Performance	References
Engineering research type	Lead crowning, tooth tip	Contact and strength performance, transmission error, NVH performance	[12]
Theoretical research type	Profile crowning, helix Crowning	Contact performance, transmission error, NVH performance	[13]
Theoretical research type	Tooth tip	Static transmission error, time-varying meshing stiffness, load distribution	[14]
Engineering research type	Lead crowning, lead slope, involute crowning	Peak-to-peak transmission error, tooth surface load, radiated noise	[15]
Engineering research type	Lead crowning, lead slope, tooth tip	Transmission error, contact spot, dynamic stiffness of bearing seat, NVH performance	[16]
Engineering research type	Tooth tip, lead crowning helix angle	Gear howling, transmission error, vibration noise	[17]
Engineering research type	Lead relief, lead crowning, tooth. end, tooth tip	Contact performance, transmission error, structural noise	[18]

essential processes for improving the machining accuracy and surface quality of gears for new energy vehicles due to their notable advantages in high efficiency and precision in high-precision gear machining [21]. In actual production, the scientific selection between grinding and power gear honing must consider multiple factors such as specific technical requirements, material characteristics, application scenarios, and production volume. The corresponding selection process is shown in Figure 2.

Grinding technology

According to the relative motion principle of grinding wheel (disc grinding wheel, conical grinding wheel and worm grinding wheel) and gear, gear grinding is mainly divided into generating grinding and forming grinding [22]. The principle of generating grinding is to use the meshing motion of the grinding wheel and the gear to contact the cutting edge of the grinding wheel with the tooth shape of the gear, thereby cutting out the tooth shape of the gear, as shown in Figure 3. Although generating grinding offers high machining accuracy and efficiency, and is applicable to various gear types, such as straight teeth, helical teeth, arc teeth, etc., and has a wide range of applications, but it requires high-precision equipment and technical support [23].

Chen [24] studied the key technology of grinding gear with worm wheel, established the mathematical model of worm wheel and gear, and put forward the error compensation scheme after grinding, which improved the manufacturing accuracy of gear. Yu et al. [25] established a mathematical model of gear grinding for helical gear generating grinding, studied the relationship

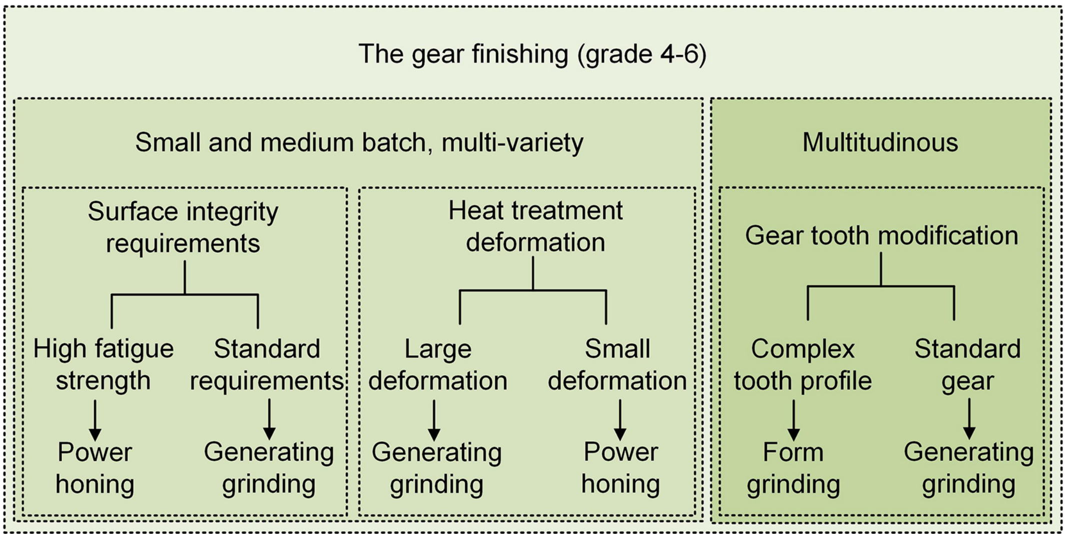

Figure 2. Selection processes of the gear finishing based on grinding and power honing

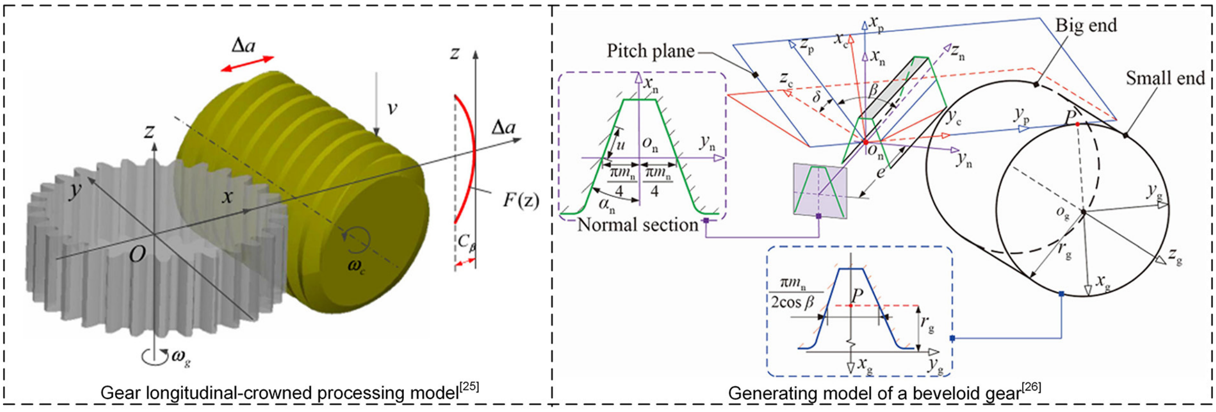

Figure 3. Gear development method machining

between tooth surface distortion and gear parameters, reduced the error of tooth surface modification, and improved the stability of gear transmission. Cao et al. [26] established a mathematical model based on the generating grinding method of bevel gears, which is used to evaluate the influence of factors such as worm wheel dressing on the accuracy of grinding gears in the grinding process, so as to effectively improve the grinding accuracy of gears. In the above research, mathematical models are established based on the generating grinding principle, and the key process parameters are optimized to improve the machining accuracy and tooth surface quality of the gear, so as to finally suppress the vibration and noise in the transmission process. At the same time, there are also some studies to improve the accuracy and bearing capacity of the gear by adjusting the spatial relationship between the grinding wheel and the machined gear or proposing new processing methods. Yoshikoto et al. [27] designed a grinding process with a large cross-axis angle between the internal gear and the grinding wheel, which not only improves the processing efficiency, but also takes into account the manufacturing accuracy of the gear. Zhang et al. [28] proposed a new method to predict the torsion of the gear flank based on the characteristics of the generating grinding, which improved the bearing capacity of the gear.

Form grinding is a kind of copying machining in essence, which has high machining efficiency [29], but it has limitations and can't process all types of gears economically and efficiently. The gear machined by form grinding is easy to produce tooth surface distortion, which affects the meshing performance of the gear. Many scholars have carried out a lot of research on this, among which grinding wheel dressing is an effective method, as shown in Figure 4. In order to solve the problem of tooth surface distortion in gear form grinding, Li et al. [30] quantified the tooth surface distortion in grinding process, and inhibited the influence of tooth surface distortion on gear meshing performance by optimizing the dressing parameters of grinding wheel. In solving the problem of tooth surface distortion, the best optimization scheme can also be sought by establishing various algorithm models. He et al. [31] used a genetic algorithm to jointly optimize the axial movement at each position when studying the twisting error in helical gear machining, which made the actually machined tooth contact trace close to the theoretical contact trace, reduced the twisting error and improved the grinding accuracy. Wang et al. [32] used neural network to optimize the parameters of the contact line optimization model of helical gear forming grinding, which improved the tooth twist phenomenon of helical gear grinding. In addition, the new machining method provides a new technical approach to address this issue, complementing the method of optimizing and compensating tooth surface distortion via algorithm models. Shih et al. [33] proposed a high-order tooth surface modification grinding method based on degrees of freedom to achieve tooth surface distortion correction, thereby improving the manufacturing accuracy of gears.

In summary, the existing generating grinding is mainly through the optimization, control of process parameters and the establishment of new processing methods to improve gear performance. Forming grinding is to optimize the process parameters by algorithm and study the tooth surface distortion mechanism to improve the gear performance. The above two gear processing

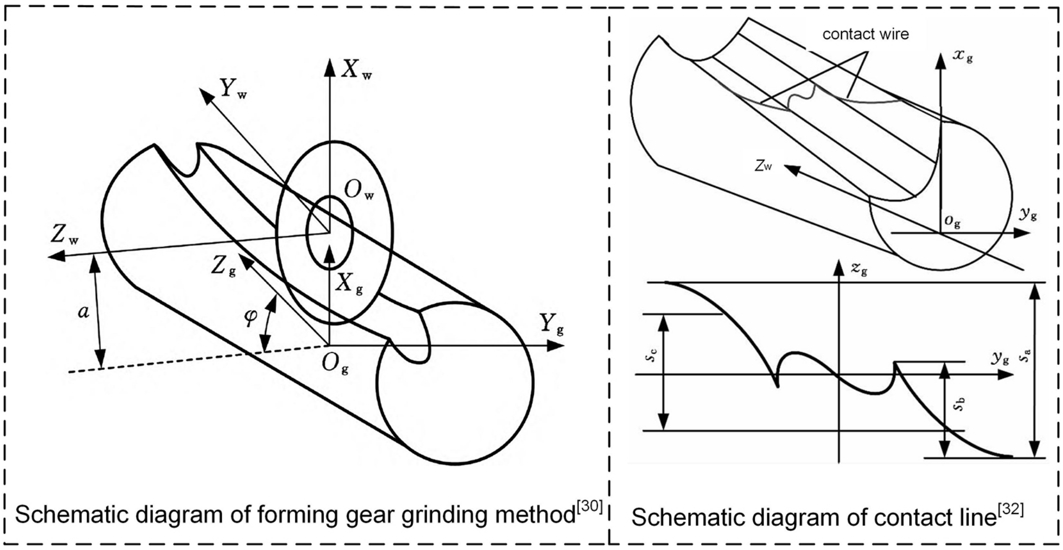

Figure 4. Gear forming method processing

methods play a vital role in enhancing gear accuracy, reducing noise, and improving transmission performance. The research on generating grinding and forming grinding in gear manufacturing is summarized in Table 2.

Honing technology

According to the meshing mode of honing wheel and workpiece gear, honing is divided into external gear honing, internal gear honing and worm wheel honing [34]. The Powerful gear honing technology is developed on the basis of conventional gear honing, integrating multi-axis synchronous control of the electronic gearbox into the machine tool [35]. This new processing method breaks through the free meshing form between the honing wheel and the processed gear in the traditional honing processing, and engages with a specific transmission ratio. The function of traditional gear honing is to deburr and refine surface texture, and the powerful gear honing can also be used to reduce the errors caused by traditional gear honing and improve

Table 2. Research on generating grinding and form grinding in gear manufacturing

Classification	Research content	References
Generative grinding	An error compensation scheme for post-grinding operations was developed, which contributed to improved accuracy in gear manufacturing.	[24]
	The relationship between tooth surface distortion and gear parameters was investigated, which reduced the error of tooth surface modification and improved the transmission stability of gears.	[25]
	This research established a mathematical model combined with the generating grinding method for bevel gears, investigating the influence of factors such as worm grinding wheel dressing on gear grinding accuracy.	[26]
	The grinding process scheme for the large intersecting shaft angle between the internal gear and the grinding wheel was investigated, which improved the gear machining efficiency and manufacturing accuracy.	[27]
	A novel method for predicting the torsion of the gear flank face was proposed, which improved the load-carrying capacity of gears.	[28]
Form grinding	The dressing parameters of the grinding wheel were optimized, which suppressed the influence of tooth surface distortion on the meshing performance of gears.	[30]
	The tooth surface contact trace was highly consistent with the theoretical contact trace, which reduced the distortion error and improved the gear grinding accuracy.	[31]
	An innovative neural network-based approach was proposed to optimize the contact line parameters in helical gear form grinding, which significantly suppressed tooth alignment distortion.	[32]
	A high-order tooth surface modification grinding method based on degrees of freedom was proposed to achieve tooth surface distortion correction, thus improving the manufacturing accuracy of gears.	[33]

the quality of tooth surface. Therefore, the powerful gear honing technology has been widely used in the gear manufacturing of new energy vehicles, especially in the field of precision reducers and gearbox gears [36].

In order to study the influence of tooth surface roughness produced by gear grinding process and power gear honing process on gear meshing noise and vibration, Jolivet et al. [37] carried out numerical simulation through the gear transmission system, and thought that reasonable selection of gear grinding and power honing process could effectively reduce gear meshing noise, subsequently, based on the multi-scale analysis of continuous wavelet decomposition, the time-frequency domain characteristics of tooth surface morphology and vibration spectrum of gear grinding and power honing transmissions are extracted to reveal the differences of different processes in reducing gear noise [38]. In order to meet the strict requirements of high-end gear manufacturing for precision control, and to deeply explore the role of powerful honing technology on gear manufacturing accuracy, Han et al. [39] first established a regression model of surface roughness by response surface method at the macro-technological level, and made clear the quantitative influence of honing wheel speed and feed on tooth surface quality, furthermore, through numerical simulation and experiment, the microscopic mechanism of motion control and machine tool adjustment errors on tooth surface profile is analyzed, and the source of machining errors is accurately identified [40], as shown in Figure 5. Silva et al. [41] conducted a series of studies with the help of internal gear honing machine tool, aiming at the tooth profile accuracy, optimized the honing process parameters through particle swarm optimization algorithm to improve the gear accuracy, through the machining experiment of small gear in steering systems, it is proved that the surface roughness of gear machined by powerful honing process is better than that of hard hobbing process [42].

In summary, the current powerful gear honing has developed from the traditional free meshing finishing to an optimized and controllable precision gear machining method. At the level of process mechanism, from macro process parameter optimization to a deeper understanding of the micro-mechanisms underlying tooth surface texture formation and machine tool motion errors is strengthened, which lays a theoretical foundation for controlling tooth surface quality. At the process control level, through the response surface method and particle swarm optimization algorithm optimization strategy, the precise control of powerful honing process parameters and machining accuracy is realized, and the stability and repeatability of the process are significantly improved. The research on power honing in terms of gear meshing noise and manufacturing accuracy is summarized in Table 3. From a production cost perspective, grinding technology, due to its high equipment depreciation and longer cycle times, is mainly applied to commercial vehicles or high-end passenger cars that require extremely high load capacity. For large-scale production focused on efficiency, hobbing is more cost-effective compared to grinding.

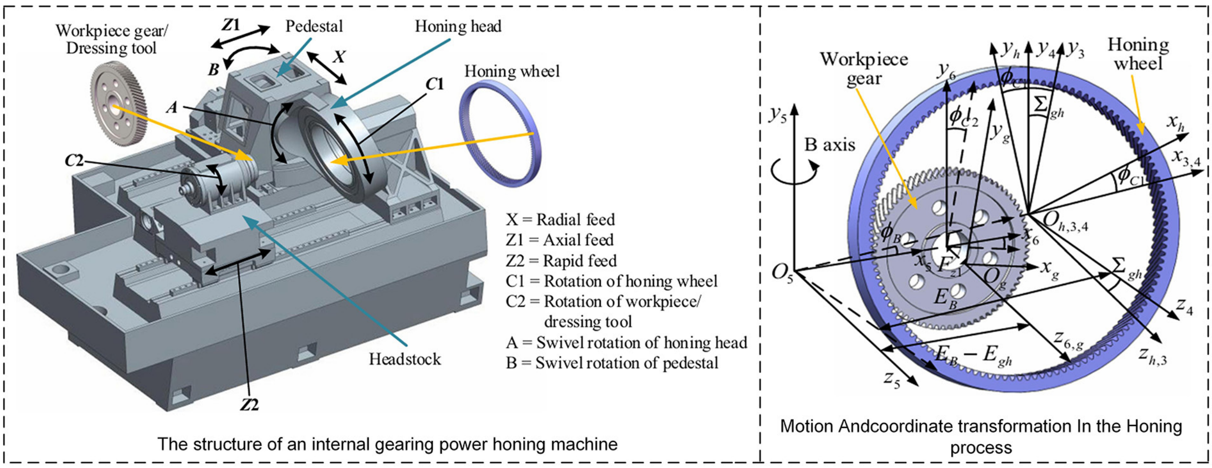

Figure 5. Honing gear processing [40]

Table 3. Research on power honing in terms of gear meshing noise and manufacturing accuracy

Classification	Research content	References
The influence of gear grinding and power honing on gear meshing noise	Through numerical simulation, it was demonstrated that both gear grinding and power honing processes can effectively reduce gear meshing noise.	[37]
	The research further clarified how gear grinding and power honing differ in their ability to reduce gear noise, demonstrating that power honing yields better results.	[38]
The influence of power honing on gear manufacturing accuracy	The quantitative influence of honing wheel speed and feed rate on tooth surface quality was clarified.	[39]
	The microscopic mechanism of action of motion control and machine tool adjustment errors on the tooth profile was analyzed.	[40]
	With the goal of tooth profile accuracy, the honing process parameters were optimized through optimization algorithms.	[41]
	Gears processed via the power honing process exhibit superior surface roughness compared to those manufactured using the hard hobbing process.	[42]

INSPECTION TECHNOLOGY OF GEAR TRANSMISSION FOR NEW ENERGY VEHICLES

Compared with fuel-powered vehicles, new energy vehicles achieve shorter acceleration time while their transmission systems are subjected to higher dynamic loads, which is more likely to cause gear performance damage and lead to a corresponding reduction in the service life of key components. To ensure the reliability of gear transmission systems and eliminate defective products during the production process, the inspection of gears for new energy vehicles is therefore particularly important. In recent years, driven by sensor technology, signal processing algorithms and artificial intelligence, two measurement methods – optical inspection [43] and deep learning [44] have become research hotspots. The typical gear inspection methods based on optics and deep learning are shown in Figure 6.

Coordinate measuring machine (CMM) inspection enables precise quantification of complex geometric features by guiding a probe to accurately position in three-dimensional space and acquiring massive discrete point cloud data. Kumar [45], Stein [46], and Chen [47] et al. proposed measurement procedures and accuracy evaluation methods for tooth surface deviations, effective contact area, calibration strategies, as well as tooth profile and helix deviations in cylindrical and helical gears using CMM. Suh et al. [48] measured tooth surface points of spiral bevel gears with CMM and applied NURBS curve fitting to the measured points. By comparing with the CAD model, they obtained deviations in tooth profile, lead, and pitch. In addition, CMM is frequently employed for experimental validation. Pisula et al. [49] designed a custom gear life test rig to analyze wear mechanisms of cylindrical gears made of different materials under load and compared the results with CMM scanning data, thereby confirming the reliability of their experimental outcomes. Shao et al. [50] developed a precise measurement model for spiral bevel gears using CMM and, based on the measurement results, proposed a high-order machine tool adjustment correction method that accounts for normal deviations of the tooth surface, enabling reverse adjustment and correction of tooth surface errors. Although CMM is currently one of the essential tools for gear accuracy inspection, the errors introduced during the measurement process still affect the accuracy of the measured results.

Laser interferometry is a high-precision inspection technology for gear geometric parameters based on optical interference, which can accurately calculate key parameters such as tooth profile error, tooth trace deviation, and cumulative pitch error. Fang et al. [51–53] first used a laser interferometer to collect interference fringe patterns and analyze the relative shape deviation between the interference fringe patterns of the measured tooth surface and the standard tooth surface; subsequently, they proposed a ray-tracing-based method to simulate the interference fringe patterns. The optical surface directly determines the feasibility, accuracy, and reliability of the measurement. To this end, Zhu et al. [54, 55] fabricated an optical surface as the measurement reference; based on the ray-tracing-based shielding analysis method, the occlusion by adjacent tooth profiles was avoided, and a complete set of tooth surface

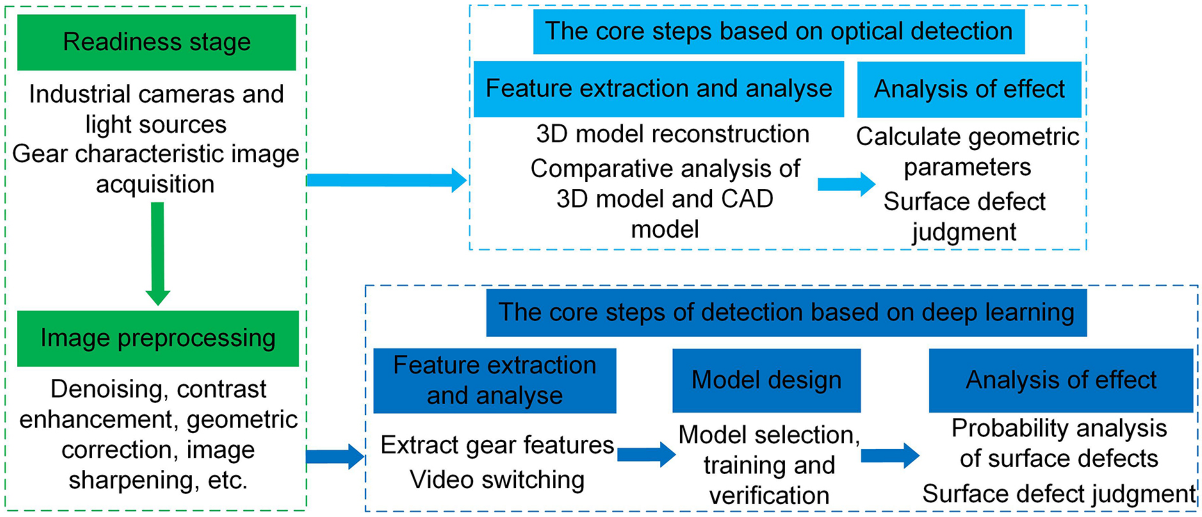

Figure 6. Typical gear inspection methods based on optics and deep learning

shape information was successfully collected, as shown in Figure 7. Urbas [56] proposed an optical three-dimensional scanning method, which was first tested on the simulated scanning data of ideal shapes with different mesh resolutions, then further validated on simulated scanning data with synthetic deviations, and finally its reliability was confirmed by comparing with coordinate measuring machine (CMM) inspection results. With the rapid development of artificial intelligence technology, deep learning has shown remarkable advantages in complex data processing, with its most prominent one being its ability to automatically extract features. Li et al. [57] proposed a convolutional neural network model based on deep learning algorithms for detecting surface scratches and missing teeth of gears. Compared with the current gear surface defect inspection technology based on machine vision, this method exhibits excellent versatility. Allam et al. [58] proposed a machine vision system using deep learning technology, which adopted the faster Region-based Convolutional Neural Network (R-CNN) to automatically identify defective gears. Zhu et al. [59] proposed an improved defect inspection model YOLO-CNF based on YOLOv5 for gear side defect inspection, with the accuracy reaching 86.7%. Qiu et al. [60] used the improved YOLOv5s for the inspection of tooth breakage, tooth surface wear, and tooth loss, which improved the gear inspection accuracy.

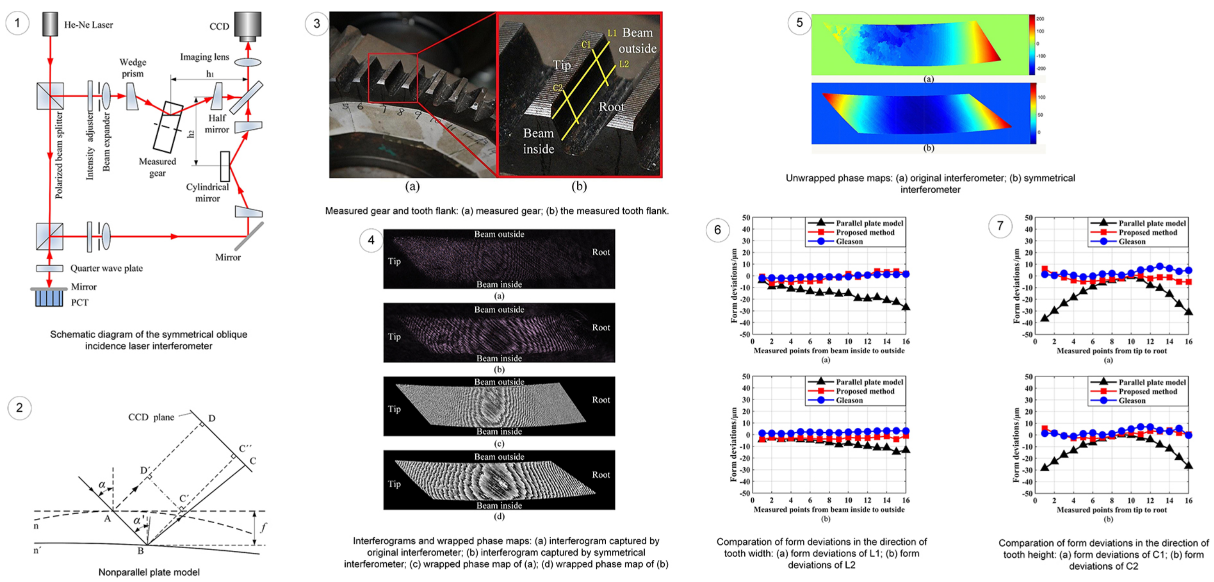

Figure 7. Tooth surface measurement steps based on symmetric laser instrument [54]

In summary, research on gear tooth surface inspection has focused on improving the accuracy, integrity, and automation level of tooth surface defect inspection. A wide range of technical approaches have been adopted, including contact-based measurement, modeling and simulation based on optical principles, and three-dimensional surface reconstruction combined with deep learning. On this basis, multiple collaborative inspection schemes that integrate digital simulation and physical measurement have been developed. The abovementioned research has broken through the bottlenecks of traditional contact measurement methods in terms of measurement accuracy, inspection efficiency, and data utilization, and promoted the development of gear inspection technology toward the direction of high precision, high efficiency, and high integration. The research on optical inspection and deep learning in gear inspection is summarized in Table 4. Contact inspection remains an important criterion, but compared to non-contact inspection, its longer inspection time cannot meet all inspection requirements. Although non-contact inspection requires higher initial investment in equipment, its high-speed characteristics allow costs to be spread over a large number of products, effectively controlling overall manufacturing costs. However, for gears with higher precision requirements, the accuracy of non-contact measurement is still insufficient.

RESEARCH PROSPECT

In summary, although significant research progress has been made in the field of gear transmission design, manufacturing and inspection technology of new energy vehicles, there are still many problems worthy of in-depth discussion. The future research focus can be summarized as the following aspects:

Intelligent gear drive designing

The development of new energy vehicles will put forward multi-dimensional ultimate performance requirements for gear transmission

Table 4. The research on optical inspection and deep learning in gear inspection

Classification	Research content	References
CMM inspection	Proposed measurement procedures and accuracy evaluation methods for gear tooth deviations, effective contact area, calibration strategies, as well as tooth profile and helix deviations	[45–47]
	Conducted measurement of spiral bevel gear tooth surfaces using CMM, applied NURBS curve fitting to the measured points, and obtained tooth profile, lead, and pitch deviations through comparison	[48]
	Analyzed the wear mechanisms of cylindrical gears made of different materials under load and compared the results with CMM scanning data to validate the reliability of experimental findings	[49]
	Developed a precision measurement model for spiral bevel gears using CMM and, based on the measurement results, proposed a high-order machine tool adjustment correction method considering normal tooth surface deviations, enabling reverse adjustment and correction of tooth surface errors	[50]
Optical inspection	Interference fringe patterns were collected using a laser interferometer, and the relative shape deviations between the interference fringe patterns of the measured tooth surface and the standard tooth surface were analyzed.	[51–53]
	An optical reference surface was fabricated as a measurement benchmark. By employing a ray-tracing-based occlusion analysis method, interference from adjacent tooth profiles was effectively avoided, thereby enabling the successful acquisition of a complete set of tooth surface shape data.	[54,55]
	An optical three-dimensional scanning method is proposed, and its reliability is verified through comparative analysis with coordinate measuring machine results.	[56]
Deep learning	A deep learning model was constructed for the inspection of surface scratches and missing teeth on gears. Compared to conventional machine vision-based approaches for gear surface defect inspection, this method exhibits superior generalizability.	[57]
	A machine vision system was proposed utilizing deep learning technology, employing an R-CNN network to automatically identify defective gears.	[58]
	An improved defect inspection model based on YOLOv5, named YOLO-CNF, was proposed for gear side surface defect inspection, achieving an accuracy of 86.7%.	[59]
	The improved YOLOv5s performs detection of broken teeth, tooth surface wear, and tooth loss, enhancing the accuracy of gear inspection.	[60]

systems, such as lightweight, low noise, and high efficiency. Nowadays, the limitations of traditional design methods are gradually becoming prominent of single-objective optimization, and multi-objective optimization and multi-disciplinary coupling models are becoming more and more important. Therefore, machine learning can be used to establish a nonlinear mapping relationship between design parameters and performance indicators, and then the gear parameter selection can be realized by swarm intelligence optimization algorithms. In addition, with sufficient sample data, machine learning and big data technology can analyze and integrate historical data, further optimize the design process and adjust the design scheme in time, as shown in Figure 8, thereby accelerating the gear transmission design process and shortening the development cycle.

Multi-energy field hybrid manufacturing of gear

Currently, the transformation and upgrading of the high-end equipment manufacturing industry is advancing towards deeper development. As one of its key sectors, the new energy vehicle industry imposes increasingly stringent requirements on gear performance. Consequently, gear manufacturing technology should not be confined to traditional mechanical processing methods but should evolve toward multi-energy field hybrid manufacturing technologies. This gear manufacturing technology can compensate for the shortcomings of conventional mechanical processing in terms of quality, precision, cost, and efficiency through the synergistic application of multiple energy fields. Compared to single-energy field approaches (such as electrochemical reactions, laser processing, or ultrasonic vibration-assisted machining), multi-energy field hybrid manufacturing enables the adjustment of material processing properties to achieve superior comprehensive outcomes. Furthermore, it is necessary to conduct in-depth research on the relationship between single or multiple special energy fields and the mechanical energy field during gear processing. This involves clarifying the processing mechanisms and material removal principles of each energy field, rationally selecting and combining special energy fields with mechanical energy fields, and elucidating the coupling relationship between them through a combination of theoretical analysis and experimental validation. Ultimately, this will enable quality control in gear manufacturing via multi-energy field processing as shown in Figure 9.

Non-contact inspection of gear

Future gear inspection will no longer be limited to geometric error analysis and other parametric assessments. Instead, it is evolving toward multi-scale integrated sensing. In terms of physical inspection, a comprehensive tooth surface information system will be constructed by integrating various non-contact sensing technologies such as laser scanning, infrared thermography, and ultrasonic testing. This will enable the inspection of gear geometric accuracy (e.g., tooth profile and helix deviations), surface integrity (e.g., roughness, micro-defects), and thermodynamic properties (e.g., temperature gradients, thermal deformation). In the inspection data processing stage, algorithms based on models such as CNN can enhance features and eliminate redundant information from multi-source inspection data,

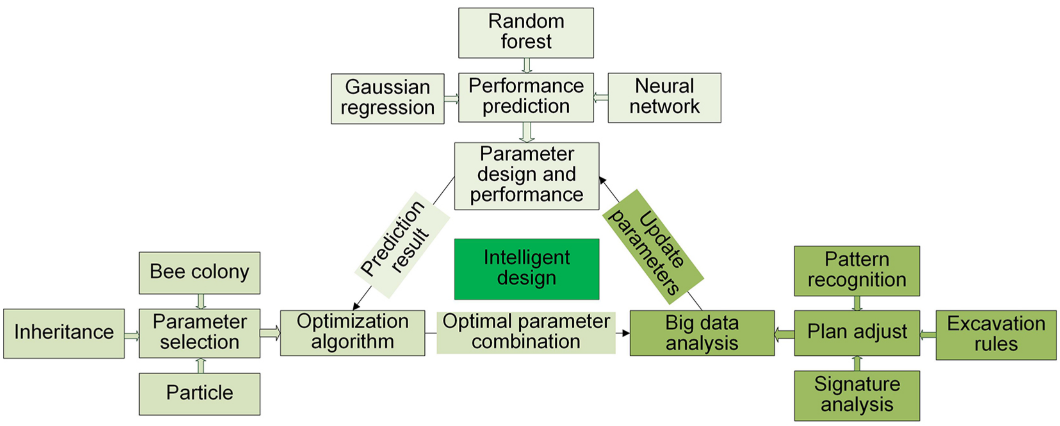

Figure 8. Collaborative design of gear transmission based on multi-objective intelligent optimization

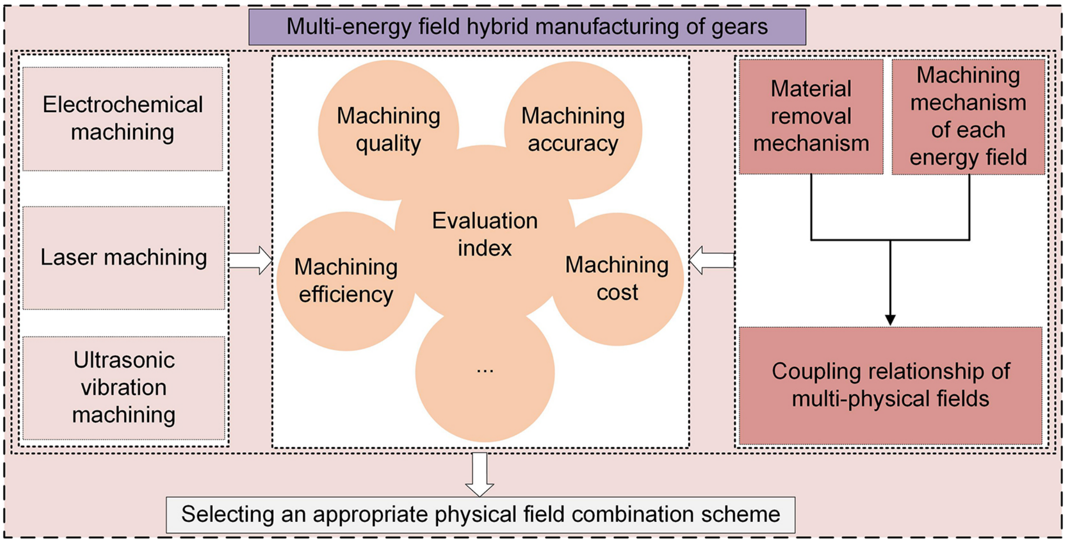

Figure 9. Technical route of multi-energy field hybrid manufacturing for gears

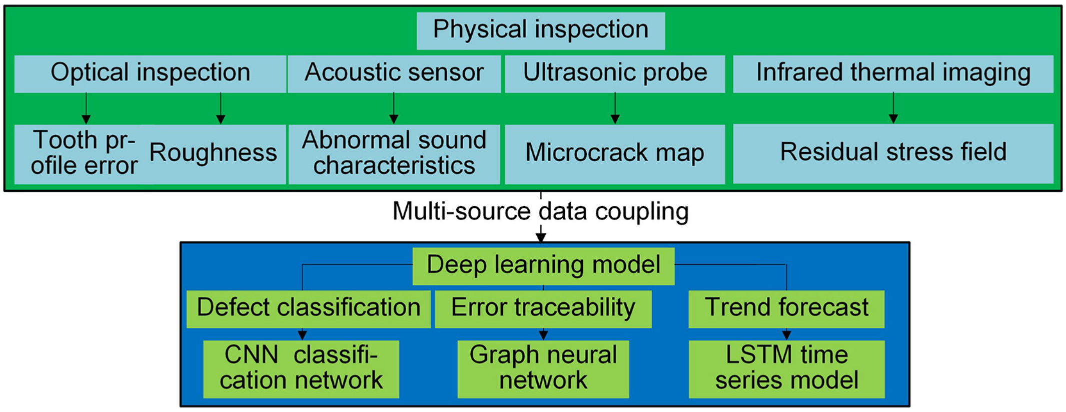

Figure 10. Multi-scale fusion-oriented non-contact inspection of gears

including visual imaging, infrared thermography, and ultrasonic imaging. This improves the usability and effectiveness of raw inspection data and facilitating the automatic identification of defects with different types and severity levels, as well as error tracing. Finally, by employing time-series prediction models, data from the entire lifecycle of gears can be integrated to forecast trends in failure modes such as tooth surface wear and crack propagation at the tooth root as shown in Figure 10.

CONCLUSIONS

This paper systematically reviews the research status and application progress of gear transmission in new energy vehicles from three aspects: design methods, manufacturing technologies and inspection technologies, and prospects the future research work. In terms of design, an intelligent integrated design for gears of new energy vehicles is established based on the multi-objective collaborative optimization theory and multi-physics field coupling modeling method. In the aspect of gear manufacturing, an appropriate multi-energy field composite manufacturing scheme is selected on the basis of research into the multi-energy field machining mechanism and material removal mechanism. In the field of inspection, defect classification, error tracing and trend prediction of gears are realized through multi-sensor physical measurement combined with deep learning models.

Acknowledgments

This work was supported by Guangxi Science and Technology Program (NOS. AD23026183 and AA24263072).

REFERENCES

1. Guo D., Chen X., Yin Y., Liu H. Research on dynamic load spectrum of electric vehicle transmission system based on underdamping characteristic. Proc. Inst. Mech. Eng., Dec. 2021, 236(14), 3296–3308, https://doi.org/10.1177/09544070211068941
2. Palermo A., Britte L., Janssens K., Mundo D., Desmet W. The measurement of Gear Transmission Error as an NVH indicator: Theoretical discussion and industrial alication via low-cost digital encoders to an all-electric vehicle gearbox. Mech. Syst. Signal Process, Sep. 2018, 110(15), 368–389, https://doi.org/10.1016/j.ymssp.2018.03.005
3. Mughal H., Sivayogan G., Dolatabadi N., Rahmani R. An efficient analytical aroach to assess root cause of nonlinear electric vehicle gear whine. Nonlinear Dyn., Sep. 2022, 110, 3167–3186, https://doi.org/10.1007/s11071-022-07800-0
4. Fang Y., Zhang T. Sound quality investigation and improvement of an electric powertrain for electric vehicles. IEEE Trans. Ind. Electron., Aug. 2017, 64(2), 1149–1157, https://doi.org/10.1109/TIE.2017.2736481
5. Machado F., Kollmeyer P., Barroso D., Emadi A. Multi-speed gearboxes for battery electric vehicles: current status and future trends. IEEE Open J. Veh. Technol., Nov. 2021, 2, 419–435, https://doi.org/10.1109/OJVT.2021.3124411
6. Hyatt G., Piber M., Chaphalkar N., Kleinhenz O., Mori M. A review of new strategies for gear production. Procedia CIRP, 2014, 14, 72–76, https://doi.org/10.1016/j.procir.2014.03.034
7. Salman W., Qi L., Zhu X., Pan H., Zhang X., Bano S., et al. A high-efficiency energy regenerative shock absorber using helical gears for powering low-wattage electrical device of electric vehicles. Energy, Sep. 2018, 159(15), 361–372, https://doi.org/10.1016/j.energy.2018.06.152
8. Jia C., He Q., Fang Z. Design and analysis of new gear with high load capacity and low slip rate. J. Huazhong Univ. Sci. Technol. (Nat. Sci. Ed.). Jun. 2024, 52(6), 87–93, https://doi.org/10.13245/j.hust.240694
9. Zhao H., Wu Q., Huang K., Qiu M., Liu P. Research status and problems of gears in China. J. Mech. Trans., Oct. 2013, 49(19), 11–20, https://doi.org/10.3901/JME.2013.19.011
10. Guo E., Liu S., Chen Z., Qiao H., Liu D., Chen M. A summary of the research on the theory and method of strong turning gear machining. J. Mech. Trans., May. 2025, 61(9), 335–349, https://doi.org/10.3901/JME.2025.09.335
11. Horvath K., Zelei A. Literature review of vibro-acoustic simulation in geared vehicle power transmission systems for the reduction of radiated noise. Adv. Sci. Technol., Jul. 2024, 153, 89–98, https://doi.org/10.4028/p-Ucpx27
12. Baek J., Gwak G., Kim N., Choi C., Lyu S. A study on the optimum micro-geometry design for strength and noise improvement. J. Korean Soc. Manuf. Process Eng., 2023, 22(1), 96–102, https://doi.org/10.14775/ksmpe.2023.22.01.096
13. Wang R., Yang C., Li J., Gong Y., Liu H., Zhang J. Study on vibration and noise analysis method of high-speed gear of electric vehicle. J. Mech. Trans., 2019, 43(4), 32–36, https://doi.org/10.16578/j.issn.1004.2539.2019.04.007
14. Zhi Y., Hao Q., Yang T. Investigation of effect of the tooth profile modification on the engagement characteristics of the gear pair. Acad. J. Sci. Technol., Nov. 2023, 8(1), 34–39, https://doi.org/10.54097/ajst.v8i1.13564
15. Wu Z. Gear modification and experimental study of two-speed transmission of electric vehicle. Jilin University, 2018.
16. Li Q., Li J., Liu J., Li Y., Zhao H. NVH simulation research and optimization of electric vehicle reducer. J. Mech. Trans., 2022, 46(2), 107–113, https://doi.org/10.16578/j.issn.1004.2539.2022.02.018
17. Zou Y. Research on improving the howling noise of transmission gears based on gear modification. South China University of Technology Guangzhou, 2018.
18. Chao X., Song C., Zhu C., Weng Y., Guo W. Effects of tooth modifications on the mesh and dynamic characteristics of differential gearbox used in electric vehicle. Iran. J. Sci. Technol. Trans. Mech. Eng., May. 2019, 43, 537–549, https://doi.org/10.1007/s40997-018-0176-7
19. Yang Y., Wu Y., Li Y., Liu X. Effects of tooth modification in the involute helical gear form-grinding process on loaded transmission character with consideration of tooth axial inclination error. Machines, Feb. 2023, 11(2), 305, https//doi.org/10.3390/machines11020305
20. Liu W. Research on measuring method and technology of cylindrical gear machining accuracy. South China University of Technology, 2021.
21. You T., Han J., Tian X., Tang J., Lu Y., Li G., Xia L. Multi-objective optimization of grinding process parameters for improving gear machining precision. J. Cent. South Univ., Mar. 2025, 32, 538–551, https://doi.org/10.1007/s11771-025-5877-7
22. Ophey M., Klocke F., Löpenhaus C. Aroach for modeling grinding worm wear in generating gear grinding. Forsch. Ing-Wes., Aug. 2017, 81, 307–316, https//doi.org/10.1007/s10010-017-0219-z
23. Wang Y., Chen Y., Zhou G., Lv Q., Zhang Z., Tang W., et al. Roughness model for tooth surfaces of spiral bevel gears under grinding. Mech. Mach. Theory, 2016, 104, 17–30, https://doi.org/10.1016/j.mechmachtheory.2016.05.016
24. Y. Chen. Research on key technologies of CNC

worm grinding wheel for modified gears. Chongqing University, 2014.

25. Yu B., Kou H., Zhao B., Shi B., Sun Y., Wu G. Aroximation model for longitudinal-crowned involute helical gears with flank twist in continuous generating grinding. Int. J. Adv. Manuf. Technol., Apr. 2021, 114, 3675–3694, https://doi.org/10.1007/s00170-021-07099-y
26. Cao B., Li G., Fortunato A., Ni H. Continuous generating grinding method for beveloid gears and analysis of grinding characteristics. Adv. Manuf., Mar. 2022, 10, 459–478, https://doi.org/10.1007/s40436-022-00388-z
27. Yanase Y., Komori M., Ochi M. Grinding of internal gears by setting a large crossed-axes angle using a barrel-shaped grinding wheel. Precis. Eng., Apr. 2018, 52, 384–391, https://doi.org/10.1016/j.precisioneng.2018.01.010
28. Zhang Z., Zhao J., Pan S., Sun X., Lu Y., Liang S. Modeling and prediction of gear flank twist for generating gear grinding. Int. J. Adv. Manuf. Technol., Jul. 2022, 121, 6751–6761, https://doi.org/10.1007/s00170-022-09765-1
29. Sun W., Zhang D., Wang X. Research on involute helical gear based on form grinding. Mech. Res. Al., 2016, 29(3), 13–16+19, https://doi.org/10.16576/j.cnki.1007-4414.2016.03.005
30. Y. Li, Z. Wang, L. Liu, X. Diao, X. Wang. Effects of tooth surfaces of topographic profile errors in double-sided grinding on gear transmission by forming method. China Mech. Eng., 2022, 33(14), 1661–1669, https://doi:10.3969/j.issn.1004-132X.2022.14.004
31. He K., Li G., Du Y., Shang N. Tooth surface distortion reduction method based on multi-axis additional motion optimization. Comput. Integr. Manuf. Syst., 2019, 25(12), 1946–1955, https://doi.org/10.16578/j.issn.1004.2539.2022.04.003
32. Wang Z., Zhu W., Li G., Geng Z. Optimization of contact line for form-grinding modified helical gears based on neural network. China Mech. Eng., 2014, 25, 1665–1671, https//doi.org/10.3969/j.issn.1004-132X.2O14.12.020
33. Shih Y., Chen S. A flank correction methodology for a five-axis CNC gear profile grinding machine. Mech. Mach. Theory, Jan. 2012, 47, 31–45, https://doi.org/10.1016/j.mechmachtheory.2011.08.009
34. Li Y. Tooth analysis on status of tooth honing process technology. Mech. Manag. Dev., Oct. 2010, 25(5), 78+81, https://doi.org/10.16525/j.cnki.cn14-1134/th.2010.05.022
35. Zhang G., Han J., Liu Y., Zhou Y. Study on heat treatment and finishing technology of hard tooth surface gear. J. Mech. Trans., 2013, 37(12), 150–152, https://doi.org/10.16578/j.issn.1004.2539.2013.12.004
36. Zhang Y., Li C., Tang Y., Cao H., Tao G. Data-driven modeling and integrated optimization of machining quality and energy consumption for internal gear power honing process. Robot. Comput. Integr. Manuf., Jun. 2025, 93, 102943, https://doi.org/10.1016/j.rcim.2024.102943
37. Jolivet S., Mezghani S., Mansori M., Zahouani H. Numerical Simulation of Tooth Surface Finish Effects on Gear Noise. ASME 2014 12th Biennial Conference on Engineering Systems Design and Analysis, Oct. 2014, 1, https://doi.org/10.1115/ESDA2014-20575
38. Jolivet S., Mezghani S., Mansori M., Jourdain B. Dependence of tooth flank finishing on powertrain gear noise. J. Manuf. Syst., Oct. 2015, 37(2), 467–471, https://doi.org/10.1016/j.jmsy.2014.11.006
39. Han J., Zhang G. Investigation on formation mechanism of surface texture and modeling of surface roughness with internal gear power honing. Int. J. Adv. Manuf. Technol., Jun. 2018, 98, 603–615, https://doi.org/10.1007/s00170-018-2265-6
40. Han J., Zhu Y., Xia L., Yuan B., Wu L. Influences of control error and setting error on machining accuracy of internal gearing power honing. Int. J. Adv. Manuf. Technol., Sep. 2019, 100, 225–236, https://doi.org/10.1007/s00170-018-2722-2
41. Santos S., Brandão L., Gallicchio L., Silveira Z. Finishing process analysis between honing and hard hobbing in pinion gears alied to a steering system. Energy Procedia., 2012, 14, 2–8. https://doi.org/10.1016/j.egypro.2011.12.888
42. Silva S., Filho S., Brandão L. Particle swarm optimization for achieving the minimum profile error in honing process. Precis. Eng., Oct. 2014, 38(4), 759–768, https://doi.org/10.1016/j.precisioneng.2014.04.003
43. Fang S., Zhu X., Yang P., Cai Q., Komori M., Kubo A. Analysis and compensation method for installation error in measuring gear tooth flank with laser interferometry. Opt. Eng., Aug. 2014, 53(8), 084112014, https//doi.org/10.1117/1.OE.53.8.084111
44. Luo S., Liao R., Zheng B. Research on surface defect inspection of transmission gear based on machine vision. Manuf. Autom., 2024, 46(3), 130–133+166.
45. Kumar P., Hirani H., Agrawal A. K. Effect of gear misalignment on contact area: Theoretical and experimental studies[J]. Measurement, Jan. 2019, 132, 359–368, https://doi.org/10.1016/j.measurement.2018.09.070
46. Stein M., Wedmann A., Jantzen S., Hierse K., Kniel K. Involute gear calibration using tactile CMMs in scanning mode[J]. Meas. Sci. Technol., 2020, 31(7), 075003, https://doi.org/10.1088/1361-6501/ab7bfe
47. Chen Y., Chen J., Optical inspection system for gear tooth flanks using a projection moiré method[J]. Sensors, Mar. 2019, 19(6), 1450, https://doi.org/10.3390/s19061450
48. Suh S. H., Lee E. S., Kim H. C., Cho J. H. Geometric error measurement of spiral bevel gears using a

virtual gear model for STEP-NC[J]. Int. J. Mach. Tools Manuf., Feb. 2002, 42(3), 335–342, https://doi.org/10.1016/S0890-6955(01)00130-4

49. Pisula J., Budzik G., Turek P., Cieplak M. An analysis of polymer gear wear in a spur gear train made using FDM and FFF methods based on tooth flank topography assessment[J]. Polymers, May. 2021, 13(10): 1649, https://doi.org/10.3390/polym13101649
50. Shao W., Ding H., Tang J. Data-driven operation and compensation approaches to tooth flank form error measurement for spiral bevel and hypoid gears[J]. Measurement, Jul. 2018, 122: 347–357, https://doi.org/10.1016/j.measurement.2018.03.004
51. Fang S., Wang L., Komori M., Kubo A. Simulation method for interference fringe patterns in measuring gear tooth flanks by laser interferometry. Al. Opt., 2010, 49(33), 6409–6415, https://doi.org/10.1364/AO.49.006409
52. Wang L., Fang S., Yang P., Meng L. Comparison of three methods for identifying fringe regions of interference fringe patterns in measuring gear tooth flanks by laser interferometry. Optik, Dec. 2015, 126, 5668–5671, https://doi.org/10.1016/j.ijleo.2015.08.177
53. Fang S., Yang P., Zhu X., Komori M., Kubo A. Form deviation measurement of helical gear tooth flank using phase-shifting laser interferometry. Lasers Eng., 2014, 29(1), 9–22.
54. Zhu X., Chen Z., Yang P., Huang X., Guo Z., Chang Z., et al. Design optical surface as the measurement datum in measuring gear tooth flank by symmetrical laser interferometer. Opt. Laser Technol., Feb. 2024, 169, 110034, https://doi.org/10.1016/j.optlastec.2023.110034
55. Zhu X., Wang Z., Yang P., Zhang P., Wang X., Zhao Z., et al. Analysis and optimization of shielding in measuring helical gear tooth flank by laser interferometry. Meas. Sci. Technol., Jun. 2022, 33(10), 105006, https://doi.org/10.1088/1361-6501/ac7a05
56. Urbads U., Zorko D., Černe B., Tavčar J., VukašinovićJože T. A method for enhanced polymer spur gear inspection based on 3D optical metrology. Measurement, Feb. 2020, 169, 108584, https://doi.org/10.1016/j.measurement.2020.108584
57. Rabiou A., Yan J., Yang H., Liu X. Gear surface defect inspection method based on convolutional neural network. Agric. Equip. Veh. Eng., Jun. 2022, 60(6), 154–157, https://doi.org/10.3969/j.issn.1673-3142.2022.06.035
58. Allam A., Moussa M., Tarry C., Veres M. Detecting teeth defects on automotive gears using deep learning. Sensors, Dec. 2021, 21(24), 8480–8480, https://doi.org/10.3390/s21248480
59. Zhu D., Cheng G., Yao J. Improved YOLOv5 surface defect inspection of automobile gear parts. Comput Eng Al., 2024, 60(5), 321–327, https://doi.org/10.3778/j.issn.1002-8331.2306-0425
60. Qiu J., Bei S., Yin M., Qing H. Gear surface defect inspection based on improved YOLOv5s. Mod. Manuf. Eng., 2022, 104–113, https://doi.org/10.16731/j.cnki.1671-3133.2022.03.016