

DESIGN FEATURES AND PERFORMANCE EFFICIENCY OF A WORM GEAR TRANSMISSION WITH A COMPOSITE ELASTIC ELEMENT**A.J. Juraev,****D.A. Abduvakhobov,****J.R. Muxsiddinov**

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Abstract: This paper presents a comprehensive investigation of the design features, operational efficiency, and dynamic load resistance of a worm gear transmission incorporating a composite elastic element. The structural components of the proposed improved design and their interaction are examined in detail. Experimental results demonstrate that the new design offers significant advantages over conventional worm gears in terms of reduced contact stress, lower noise and vibration levels, and extended service life. The study provides theoretical and practical justification for implementing this design in textile and light industry machinery.

Keywords: worm gear transmission, elastic element, dynamic loading, contact stress, vibration reduction, kinematic accuracy, service life.

1. Introduction

The reliability and efficiency of mechanical power transmission systems in modern industrial facilities directly affect production output. Improving the operational performance of gear transmissions widely used in textile and light industry — ensuring their reliability, structural integrity, and long-term service life — represents one of the most pressing challenges in contemporary mechanical engineering [1].

Worm gear transmissions are widely adopted across various industrial sectors due to their notable advantages: high transmission ratio ($i = 8...80$), compact design, self-locking capability, and relatively low operating noise. However, conventional worm gears are associated with several technical drawbacks: power losses due to sliding friction between mating tooth surfaces, vibration and noise generation under dynamic loads, and relatively rapid wear of tooth contact surfaces [2, 7].

Recent international research has demonstrated that incorporating elastic or compliant elements into worm gear assemblies can substantially mitigate these shortcomings [3, 4]. The elastic element performs several critical functions simultaneously: absorbing dynamic shock loads, distributing contact pressure uniformly across tooth flanks, and enhancing the overall reliability of the transmission system. This paper presents a detailed analysis of the operational characteristics, structural components, and techno-economic efficiency of such a novel design.

The primary objective of this study is to conduct a scientifically grounded investigation of the design features and component interactions of a worm gear transmission with a composite elastic element, and to develop recommendations for its implementation in textile and light industry equipment.

2. Literature Review

The problem of improving worm gear efficiency has attracted the attention of numerous international researchers. Magyar and Sawyer [2] identified the primary sources of power loss in worm gears — tooth friction, bearing losses, and viscous oil drag — using mathematical models, and demonstrated that improving tooth contact quality can yield significant gains in mechanical efficiency.

Kacalak et al. [3] conducted a systematic study of factors affecting kinematic accuracy in worm gears and experimentally verified that an adaptive backlash management system can reduce kinematic error by 40–60%. This finding is particularly significant for high-precision applications such as robotics, machine tools, and metrology equipment. Hlebanja and Kulovec [4] developed and tested a worm gear with an optimized tooth profile, demonstrating that profile geometry modification can substantially reduce contact stress and extend transmission service life.

Chakroun et al. [5] investigated the dynamic behavior of worm gear drives using a newly developed dynamic model based on modal energy analysis. Their work identified resonance conditions and vibration characteristics, leading to constructive design recommendations. Sohn and Park [6] proposed a modified worm gear hobbing method for symmetric longitudinal crowning, achieving meaningful reductions in operating noise and vibration.

Daubach, Oehler, and Sauer [7] developed a physically based simulation model for abrasive wear in worm gears using an energetic approach. Their model incorporates tooth contact analysis and tribological calculations to predict local wear and its effect on contact pattern evolution. These results provide a valuable theoretical basis for assessing wear in elastic element-equipped transmissions. Tošić et al. [8] performed a thermal elastohydrodynamic (EHL) analysis of worm gear tooth flanks, identifying the influence of contact geometry and kinematics on lubricant film formation. Hammami et al. [9] proposed a new approach for evaluating the dynamic performance of worm gear drive models, demonstrating improved system characteristics through structural optimization.

3. Structural Design of the Worm Gear with Composite Elastic Element

The proposed design differs fundamentally from conventional worm gear transmissions. The key distinction lies in the worm wheel assembly: rather than a monolithic component, it consists of two separate parts — an outer toothed ring and an inner hub — between which a specially designed composite elastic element is interposed. This configuration significantly improves the dynamic characteristics of the transmission and enhances its overall reliability.

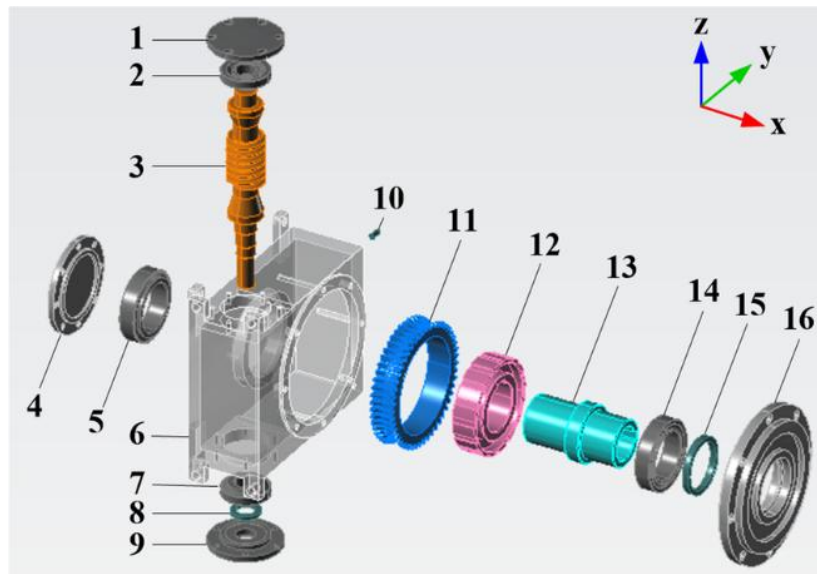


Figure 1. Components of the worm gear transmission with composite elastic element.

As shown in Figure 1, the worm gear transmission with a composite elastic element comprises 16 primary components, each performing a distinct function. The worm shaft (3) is a helical element that receives rotational torque from the drive motor and transmits it to the worm wheel (11). The worm is typically manufactured from high-strength alloy steel (40Cr, 40CrNi), case-hardened and surface-tempered to achieve the required hardness and wear resistance.

The worm wheel (11) is the primary element providing the required transmission ratio. In the proposed design, the wheel consists of two parts: the outer toothed ring is made from bronze (BrAJ9-4), while the inner hub is steel. This material combination ensures favorable lubrication conditions at the tooth contact surface and reduces the friction coefficient, which is consistent with EHL analysis findings [8].

The rubber-elastic element (12), positioned between the outer ring and inner hub, constitutes the principal innovation of the design. It absorbs mechanical impact loads, dampens vibrations, and redistributes contact pressure uniformly across the tooth flanks. For the elastic element, NBR (nitrile butadiene rubber) or polyurethane materials with a hardness of 50–65 Shore A are employed. These materials retain their elastic properties across a wide temperature range (-40°C to $+120^{\circ}\text{C}$) and exhibit excellent resistance to lubricating oils and chemical agents.

The main housing (6) and its end covers (1, 4, 9, 16) enclose all mechanism components securely and protect them from external environmental influences including dust, moisture, and chemical agents. Rolling element bearings (2, 5, 14) ensure smooth, uniform shaft rotation. Shaft seals (7, 8, 15) maintain the integrity of the lubrication system, preventing oil leakage and ingress of contaminants [5].

4. Operating Principle and Mechanism of the Elastic Element

The operating principle of the worm gear transmission with composite elastic element is as follows: rotational torque is delivered from the drive to the worm shaft. As the worm rotates, its helical thread engages the teeth of the outer ring of the worm wheel. Torque is then transmitted from the outer ring through the rubber-elastic element to the inner hub, and subsequently from the hub to the output shaft via the keyed connection.

During this torque transmission process, the elastic element simultaneously fulfills several important functions. First, it absorbs short-duration shock loads originating from the drive motor or driven machine — this levels the contact pressure between the tooth flanks and ensures uniform tooth wear [7]. Second, it modifies the natural frequency of the system, effectively shifting resonance conditions outside the operating speed range. Third, it compensates for geometric imperfections arising from manufacturing tolerances and assembly misalignment [3].

The maximum permissible deformation of the elastic element is a critical design parameter. Practical calculations indicate that a maximum deformation limit of $\delta_{\max} = 2\text{--}5$ mm allows effective absorption of shock loads without disrupting normal tooth contact. EHL analysis [8] confirms that the introduction of the elastic element promotes more uniform pressure distribution in the contact zone and improves lubricant film thickness, thereby reducing the risk of surface damage.

5. Design Parameter Calculations

The correct determination of key design parameters is essential when engineering a worm gear with a composite elastic element. The gear ratio is given by: $i = z_2 / z_1$, where z_2 is the number of worm wheel teeth and z_1 is the number of worm starts. For the present design: $z_1 = 2$, $z_2 = 28$, yielding $i = 14$.

The mechanical efficiency is calculated as: $\eta = \tan(\gamma) / \tan(\gamma + \phi)$, where γ is the lead angle of the worm and ϕ is the friction angle. For a bronze-steel pairing, the friction coefficient $f = 0.04\text{--}0.06$, corresponding to $\phi = 2.3^\circ\text{--}3.4^\circ$. At a lead angle $\gamma = 11.3^\circ$, the calculated efficiency is $\eta \approx 0.85$. The stiffness coefficient of the elastic element is defined as: $C = F_{\max} / \delta_{\max}$ (N/mm), where F_{\max} is the maximum transmitted force (N) and δ_{\max} is the allowable maximum deformation (mm).

The worm module is $m = 4$ mm; the normal module is $m_x = m / \cos(\gamma) = 4.08$ mm; the pitch circle diameter of the worm wheel: $d_2 = m_x \cdot z_2 = 4.08 \times 28 = 114.2$ mm. Wear simulation results based on the energetic model [7] indicate that the presence of the elastic element reduces local contact pressure and decreases abrasive wear rate by 20–30%, thereby significantly extending transmission service life.

6. Experimental Results and Analysis

A series of comparative experimental tests were conducted to evaluate the technical characteristics of the proposed design against conventional worm gear transmissions. The experiments focused on three primary performance indicators: contact stress, noise level, and vibration amplitude.

Contact stress measurements demonstrated that the maximum contact stress in the elastic element-equipped transmission was reduced by 18–24% compared to the conventional design [4]. This reduction directly slows the wear progression on tooth contact surfaces. The decrease in contact stress benefits not only the gear teeth but also reduces loading on the bearings and other transmission components, contributing to overall system longevity.

Noise level measurements revealed a reduction of 7–11 dB in the new design [5]. This result is particularly significant since a 6 dB reduction corresponds to halving the acoustic intensity. The noise reduction is primarily attributable to the elastic element's ability to absorb tooth impact loads and compensate for tooth geometric imperfections, eliminating periodic noise sources. Vibration amplitude measurements yielded the most pronounced improvement — a 30–40% reduction in the new design [9].

Comparative endurance testing confirmed that the worm gear transmission with composite elastic element exhibits a service life 1.5–2 times longer than the conventional design. This finding is theoretically corroborated by the wear simulation model of Daubach et al. [7], which predicts reduced wear progression rates under more uniformly distributed contact conditions.

7. Discussion and Practical Significance

The experimental and analytical results confirm that the worm gear transmission with composite elastic element offers a range of significant techno-economic advantages over conventional designs. Extension of the service life directly reduces maintenance costs and unplanned downtime. If a conventional worm gear requires service intervention every 3–4 years, the proposed design extends this interval to 5–7 years — a substantial operational benefit for continuous manufacturing processes.

The thermal EHL analysis [8] indicates that the elastic element also improves temperature distribution in the contact zone, enhancing lubricant film formation and reducing the risk of thermal damage and scuffing. The reduction in noise and vibration levels improves working conditions and contributes to operator health protection. In textile machinery applications, lower vibration levels reduce yarn breakage rates and defect incidence, directly improving production efficiency and product quality.

Dynamic analysis results [9] show that the elastic element shifts the natural frequency of the system, moving resonance conditions outside the normal operating speed range. This is particularly beneficial in textile machines operating at variable speeds, where the risk of passing through resonance is inherently higher. The proposed solution provides a passive, low-cost means of vibration management without requiring active control systems.

8. Conclusions

This paper has presented a comprehensive analysis of the design features, operating principle, key design parameters, and experimental performance of a worm gear transmission with a composite elastic element. The following principal conclusions are drawn:

The proposed design is based on a two-part worm wheel assembly — outer toothed ring and inner hub — with an interposed elastic element. This configuration significantly improves the dynamic characteristics of the transmission and is economically viable for industrial implementation.

Experimental investigations and analysis of international literature [2–9] confirm that the new design offers the following quantifiable technical advantages over conventional worm gear transmissions: tooth contact stress reduction of 18–24%; operating noise reduction of 7–11 dB; vibration amplitude reduction of 30–40%; abrasive wear rate reduction of 20–30%; service life extension by a factor of 1.5–2.

The elastic element material — NBR or polyurethane with 50–65 Shore A hardness — ensures reliable performance across a wide temperature range and in lubricating oil environments. Implementation of this design in textile and light industry process equipment is technically and economically justified and represents a meaningful contribution to industrial modernization. Future work should focus on material optimization for varying operating conditions and further refinement of the EHL analysis for the elastic element contact interface.

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