EXPERIMENTAL OPTIMIZATION OF FINISHING PARAMETERS FOR IMPROVED ACCURACY AND SURFACE QUALITY OF SPUR GEAR TEETH

B. K. Shakulov,
Process Engineer, GIDRO STANKO SERVIS LLC, Uzbekistan
B. T. Mardonov
Rector, Doctor of Technical Sciences (DSc), Professor, Navoi State University of Mining and Technologies, Navoi, Uzbekistan

Abstract. *This study investigates the optimization of finishing parameters for improving the dimensional accuracy and surface quality of spur gear teeth processed by a combined shaving–rolling method. The experiments were conducted on a Vturn-46 CNC lathe using a specially designed two-axis fixture and a shaving–rolling tool manufactured from R6M5 high-speed steel. Spur gears made of 40Cr steel, with a module of 3 mm, 24 teeth, and a profile-shift coefficient of 1.4, were used as test specimens. Three workpiece rotational speeds—700, 450, and 200 rpm—were evaluated under constant feed conditions. Ten specimens were processed at each rotational speed to assess the repeatability of the results. Gear accuracy and flank surface roughness were used as the principal quality indicators. The experimental findings demonstrated that a reduction in rotational speed improved both parameters. Processing at 700 and 450 rpm produced an accuracy grade of 6–7 and an average surface roughness of R_a=1.6 μm . The best performance was achieved at 200 rpm, resulting in grade 6 accuracy according to GOST 1643-83 and a surface roughness of Ra=0.8 μm. The results confirm that shaving–rolling can be effectively implemented on universal CNC lathes as an alternative finishing method for the batch production of spur gears.*

Keywords:*Spur gears; shaving–rolling process; gear finishing; machining parameters; tooth flank accuracy; surface roughness; CNC turning.*

1. Introduction

The production of cylindrical gears is a technically demanding process because the operational performance of a gear transmission largely depends on tooth-profile accuracy and flank surface quality. Conventional gear manufacturing usually involves several machining stages and requires specialized equipment, particularly during semi-

finishing and finishing operations. These requirements increase production costs and may limit manufacturing flexibility, especially in small-batch and medium-scale production.

Various finishing techniques have been developed to improve the geometrical accuracy and surface condition of gear teeth. Among them, shaving–rolling combines material removal with controlled plastic deformation of the tooth flanks. This combined action can reduce surface irregularities, strengthen the near-surface layer, and improve the accuracy of the involute profile. Previous studies have demonstrated the technological potential of rolling-type tools in the finishing of cylindrical gears [1, 2]. However, the final machining quality depends considerably on the selected processing parameters and the stability of the relative motion between the tool and workpiece.

A specially designed shaving–rolling tool makes it possible to perform gear-finishing operations on a universal CNC lathe instead of a dedicated gear-finishing machine. A two-axis fixture provides secure workpiece positioning and ensures the required interaction between the gear and the rolling tool. Nevertheless, the influence of workpiece rotational speed on the resulting accuracy and surface roughness requires experimental evaluation before this method can be reliably introduced into production.

Therefore, the objective of this study is to determine the most effective rotational speed for the finishing of spur gear teeth using an R6M5 high-speed-steel shaving–rolling tool. The investigation compares three rotational speeds under fixed feed conditions and evaluates their influence on gear accuracy and tooth-flank roughness. The results are intended to establish practical processing parameters for producing spur gears with improved surface quality on universal CNC equipment.

2. Materials and Methods

Experimental trials were performed on spur gears manufactured from 40Kh steel in accordance with GOST 4543-71. The specimens had a normal module of m=3, z=24 teeth, and a profile-shift coefficient of x=1.4. Before finishing, the gear teeth were produced by hobbing and subsequently surface-hardened through high-frequency induction heating.

The finishing operation was carried out on a Vturn-46 CNC lathe. Each workpiece was mounted in a specially developed two-axis fixture and supported by the tailstock centre to maintain stable positioning during machining. A combined shaving–rolling tool made of R6M5 high-speed steel was installed in the turret using a dedicated tool holder. During operation, the tool interacted with the gear teeth at predetermined centre distances. These distances were gradually reduced between working cycles through an intermittent infeed motion.

The effect of workpiece rotational speed was evaluated at three levels: 700, 450, and 200 rpm. The radial infeed was maintained at 0.03 mm per cycle, while the intermittent feed was fixed at 0.03 mm per working cycle. Ten gear specimens were machined under each condition, resulting in a total of 30 experimental samples. This repeated-trial procedure was used to evaluate the consistency of the finishing results and reduce the influence of random variation.

The quality of the finished gears was assessed using two principal indicators: tooth accuracy grade according to GOST 1643-83 and arithmetic mean roughness R_a of the tooth flanks. The results obtained at the three rotational speeds were compared to identify the processing condition that provided the most favourable combination of geometrical accuracy and surface finish.

3. Results

The experimental results showed that workpiece rotational speed influenced both the accuracy grade and surface roughness of the finished gear teeth. The results obtained under the three investigated machining conditions are summarized in Table 1.

Table 1. Effect of workpiece rotational speed on gear-finishing quality

Workpiece speed, rpm	Radial infeed, mm/cycle	Intermittent feed, mm/cycle	Accuracy grade, GOST 1643-83	Surface roughness Ra, μm
700	0.03	0.03	6–7	1.6
450	0.03	0.03	6–7	1.6
200	0.03	0.03	6	0.8

At rotational speeds of 700 and 450 rpm, the processed gears reached accuracy grades of 6–7, while the measured tooth-flank roughness was Ra=1.6 μm. No observable improvement in the recorded quality indicators was obtained when the rotational speed was reduced from 700 to 450 rpm.

A further reduction to 200 rpm produced the best result among the investigated conditions. At this speed, the gears consistently achieved grade 6 accuracy, and surface roughness decreased to Ra=0.8 μm. Thus, compared with the two higher-speed conditions, machining at 200 rpm reduced the recorded roughness value by 50% and provided a more consistent accuracy grade.

These findings identify 200 rpm as the most effective rotational speed within the tested range when the radial and intermittent feeds are maintained at 0.03 mm per working cycle.

4. Discussion

The results indicate that reducing the workpiece rotational speed improved the quality of spur gear teeth finished by the shaving–rolling process. Although the experiments did not include direct measurements of contact force or temperature, the improvement observed at 200 rpm may be associated with more stable engagement between the tool and the tooth flanks. A lower rotational speed can provide sufficient time for controlled contact deformation and gradual correction of surface irregularities during each working cycle.

The identical results obtained at 700 and 450 rpm suggest that reducing the speed within this interval was insufficient to change the surface-formation mechanism substantially. Under these conditions, the gears achieved an accuracy grade of 6–7 and a roughness value of Ra=1.6 μm. At 200 rpm, however, roughness decreased to Ra=0.8 μm , while the accuracy improved to grade 6. This outcome suggests that excessive rotational speed may reduce the stability of tool–workpiece interaction and limit the corrective effect of the shaving–rolling tool.

The findings are consistent with the technological principles of combined shaving and rolling reported in previous gear-finishing studies [1, 2]. In this process, cutting action removes small surface irregularities, while rolling action promotes controlled plastic deformation of the tooth flanks. The use of a stable two-axis fixture also contributes to maintaining the required relative position of the tool and workpiece, which is essential for controlling the involute tooth profile [3].

An important practical advantage of the proposed method is its compatibility with a universal CNC lathe. Therefore, manufacturers may perform gear-finishing operations without investing in a dedicated shaving machine, particularly in batch and small-series production. Nevertheless, the identified condition should be considered optimal only within the investigated parameter range. Further research should examine additional rotational speeds, feed values, gear geometries, workpiece materials, tool wear, machining forces, and surface-layer hardness to establish broader processing recommendations.

5. Conclusion

The experimental investigation demonstrated that the combined shaving–rolling method can be effectively applied to the finishing of spur gears on a universal CNC lathe. Workpiece rotational speed was found to be an important parameter affecting both tooth-flank accuracy and surface roughness.

Among the investigated conditions, a rotational speed of 200 rpm, a radial infeed of 0.03 mm per cycle, and an intermittent feed of 0.03mm per working cycle provided the best machining performance. Under these conditions, the finished gears achieved grade

6 accuracy according to GOST 1643-83 and a surface roughness of Ra=0.8 μm. In comparison, rotational speeds of 450 and 700 rpm resulted in accuracy grades of 6–7 and a roughness value of Ra=1.6 μm.

Therefore, 200 rpm can be regarded as the optimal workpiece rotational speed within the tested range. The proposed finishing method offers a practical alternative to specialized gear-finishing equipment and may be particularly suitable for the small-batch and batch production of spur gears.

References

1. Mardonov, B. T. (2018). Control of machining accuracy of the involute profile along the gear tooth height. *Universum: Technical Sciences*, 8(53), 9–12.
2. Juraev, A.D., Davidbayev, B.N., Juraev, N.N., Beknazarov, J.K., E3S Web of Conferences, 414, 06005 (2023)
3. Маликов А.А., Валиков, Е. Н., Ямников, А. С. (2007). Прогрессивная технология зубообработки. Известия Орловского государственного технического университета. Серия: Фундаментальные и прикладные проблемы техники и технологии, (4-3), 107-110.
4. Маликов, А. А., Сидоркин, А. В. (2008). Шевингование прикатывание цилиндрических колес с круговыми зубьями. Известия Тульского государственного университета. Технические науки, (2), 69-75.