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EXPERIMENT PREPARATION FOR LASER-CUT SPUR GEARS EFFICIENCY TESTING

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Abstract: *Cylindrical spur gears remain widely used in mechanical systems due to their simplicity and effectiveness, despite being a long-established component in engineering. While many aspects of spur gear design, analysis, and application have been thoroughly studied during decades, recent research trends have shifted toward optimizing manufacturing efficiency and reducing production costs. This paper presents the preparation of laser-cut spur gears for the purpose of evaluating their power transmission efficiency. The gears were produced using laser cutting technology, which offers potential advantages in terms of production speed and cost-effectiveness compared to conventional manufacturing methods. The experimental evaluation is planned to be conducted using the GUNT AT200 test rig, where the gears will be mounted on test gearboxes. Multiple gear pairs with identical center distances will be examined under controlled conditions to assess their mechanical efficiency. The primary objective is to determine whether laser-cut gears, despite potential limitations in precision and surface finish, can achieve acceptable performance for practical applications, particularly in prototyping and low-load scenarios.*

Keywords: *spur gears; efficiency testing, test rig, laser-cut gears.*

1. INTRODUCTION

Gears are fundamental components in mechanical engineering, designed to transfer motion and torque efficiently between rotating shafts. A gear typically consists of a central body and a toothed rim, where the teeth are geometrically distributed to ensure smooth meshing and load transmission. The field of gear geometry focuses on defining the shape and dimensional characteristics of these teeth, which directly affect performance parameters such as efficiency, wear, and operational lifespan. Among various profile types, involute and cycloidal gears are the most prevalent, with involute gears widely favored due to their consistent transmission ratio and manufacturability. In this paper, the gears are produced from flat steel plate by laser cutting method.

Conventional gear manufacturing involves methods such as hobbing, shaping, and milling. While these techniques offer high precision, they also require significant time and cost, especially in small-batch or prototype production. In response, modern manufacturing seeks alternatives that enable faster and more economical fabrication. Laser cutting has emerged as one such method, offering speed, flexibility, and reduced tooling complexity. However, existing literature on laser-cut gears is largely limited to small-scale gears (outer diameters below 9.04 mm), typically made from stainless steel and intended for lightweight applications [1–4].

The present study extends this research by investigating the production and dimensional quality of laser-cut spur gears of varying sizes and materials. A streamlined fabrication approach was adopted to minimize time and cost while ensuring sufficient geometric accuracy. Post-processing measurements were conducted using precision metrology tools to evaluate the resulting gear dimensions and profile conformity. Multiple gear samples were analyzed, and their geometric properties compared to assess the influence of cutting parameters, material selection, and gear size on manufacturing quality [5–6].

Previous papers such as [7] explored laser beam machining of miniature gears with emphasis on surface integrity and burr formation, while [8] focused on the operational efficiency of non-metallic meshing elements in gear reducers. Building on these directions, this paper investigates not only the manufacturing outcomes but also the functional evaluation of laser-cut gears under load.

As part of this research, six gear pairs with identical center distances were designed and fabricated using laser cutting. These gear sets have been mounted onto dedicated test gearboxes, and preparation has been completed for efficiency testing using the GUNT AT200 apparatus. Each gear pair will undergo individual testing under controlled conditions, enabling the quantification of mechanical efficiency and performance. This experimental phase aims to validate the viability of laser-cut gears for use in functional, low-load transmission systems and provide comparative insight into the suitability of different gear configurations.

2. DESIGN PARAMETERS OF THE SPUR GEARS FOR EFFICIENCY TESTING

In preparation for this research, six gear pairs (twelve individual gears) were designed, all with a fixed center distance of 80 mm, but with different transmission ratios. The gear geometries were modelled using Autodesk Inventor 2019, where each pair was designed to ensure accurate meshing under experimental conditions.

To ensure the highest fidelity of the tooth profile, the "Export Tooth Shape" function within the software was used (Figure 1). This tool exports the true involute geometry of gear teeth and avoids approximations inherent in generic CAD features. Without this export function, the resulting tooth profiles would deviate from the theoretical involute, which could lead to meshing issues or incorrect load distribution during testing.

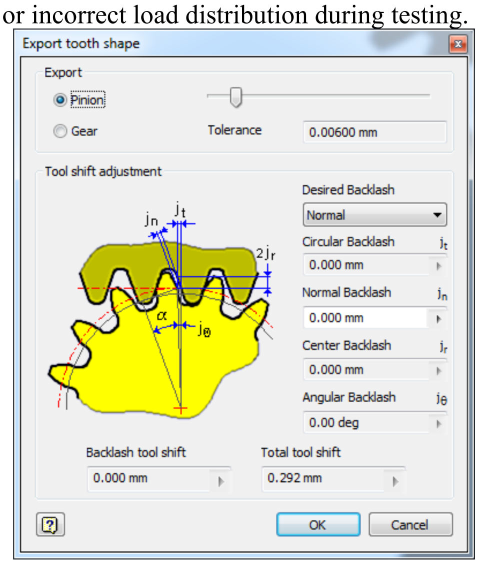

Fig. 1. Tooth profile generation using the Export Toot Shape function in Autodesk Inventor

The gear pairs were carefully selected to provide a range of transmission ratios, enabling an evaluation of performance under different kinematic conditions, while maintaining a constant center distance. Each gear pair consists of a driving gear and a driven gear, designed with a consistent module but varying tooth count.

Table 1 presents the fundamental geometric parameters of each gear pair: module m, number of teeth z, pitch diameter d, addendum diameter d_a, dedendum diameter d_f, and gear ratio u. The gear pairs are denoted as 1–6 (driving) and 1′–6′ (driven), corresponding to each test configuration.

Table 1. Basic parameters of the gear pairs

$a_{1,2}$ = 80 mm (const.)							
No.	**Gear**	***m***	***z***	***d* (mm)**	**d_a (mm)**	**d_f (mm)**	**$u_{1,2}$**
1	1	3	26	78	83.977	70.5	
2	1'	3	27	81	88	74.523	1.04
3	2	2.75	26	71.5	76.994	64.625	
4	2'	2.75	32	88	94	81.631	1.23
5	3	2.75	24	66	71.494	59.125	
6	3'	2.75	34	93.5	99.5	87.131	1.42
7	4	2.5	25	62.5	67.5	56.25	
8	4'	2.5	39	97.5	102.5	91.25	1.56
9	5	2.5	23	57.5	62.5	51.25	
10	5'	2.5	41	102.5	107.5	96.25	1.78
11	6	2.25	24	54	58.499	48.375	
12	6'	2.25	47	105.75	110.5	100.376	1.96

The gear sets were designed with the intention of gradually increasing the transmission ratio in increments of approximately 0.2 between each test configuration. This incremental approach allows for a systematic analysis of efficiency variation as a function of transmission ratio. While exact steps of 0.2 were the target, slight deviations occurred due to the discrete nature of gear tooth counts and the requirement to maintain a constant center distance. Nevertheless, the selected configurations closely approximate the intended progression and provide a reliable basis for comparative evaluation.

3. LASER-CUT GEAR PREPARATION

The gears used in this study were manufactured using a high-precision laser cutting process, which is particularly suitable for creating complex profiles like involute teeth. The machine used was a BODOR C6 laser cutter, equipped with a fiber laser source optimized for cutting carbon steel plates with high accuracy.

The gear blanks were cut from S355 structural steel, a commonly used material in mechanical components due to its good balance of strength, machinability, and cost. The material thickness was 10 mm, and all laser-cutting operations were performed using the following parameters, given in Table 2.

Table 2. Laser-cut parameters

/	Laser cut parameters	Value
1	Thickness	10 mm
2	Speed	2.2 m/min
3	Power	7200 W
4	Frequency	5000 Hz
5	Duty cycle	100%
6	Cut height	1 mm
7	Nozzle	D-1.2 mm
8	Cut focus	8 mm
9	Gas pressure	0.9 bar
10	Gas type	Oxygen

These parameters were chosen to achieve the best possible quality for gear contours, ensuring sharp edges and minimal thermal distortion. The cutting focus and cut height were carefully calibrated to maintain consistent kerf width and avoid excessive burr formation.

The tolerances expected from this laser cutting setup are within ±0.1 mm for overall dimensions and ±0.05 mm for the tooth profiles. While laser cutting offers a high degree of precision, small deviations may still occur due to material warping, laser beam divergence, or uneven heat distribution. These deviations are particularly relevant in gear production, where even minor geometric inaccuracies can affect meshing behavior and efficiency.

Previous research [7,8] has demonstrated the feasibility of using laser cutting for producing both miniature and full-scale gears. These studies examined surface roughness, thermal effects, and tooth engagement behavior, confirming that laser-cut gears can be functionally comparable to traditionally machined ones—especially for low- to medium-load applications.

Figure 2 shows the laser-cut gear pairs fabricated for the experimental evaluation.

Fig. 2. Laser-cut produced spur gear pairs

After the laser cutting process, the gear blanks were manually de-burred using a belt sander to remove any residual slag or burrs that may have formed along the tooth edges. This post-processing step was essential to ensure smooth meshing between gear pairs and to minimize premature wear during efficiency testing. The use of the belt sander provided a quick and effective surface cleanup, especially along the root and flank areas of the teeth, without compromising the geometric accuracy of the profile.

4. PREPARATION OF TEST ASSEMBLIES FOR THE GUNT AT200

In order to evaluate the mechanical efficiency of laser-cut spur gears, a series of experimental tests was prepared using the GUNT AT200 apparatus (Figure 3).

Fig. 3. GUNT AT 200 Determination of gear efficiency

The GUNT AT200 is a didactic test rig designed for analyzing gear efficiency under controlled conditions. It allows precise measurements of input and output torque, rotational speeds, and mechanical losses across the gear stage.

4.1 Gear Assembly and Installation

Each of the six laser-cut gear pairs was mounted in a dedicated test gearbox module supplied with the GUNT system. The gearboxes were disassembled to allow precise shaft alignment and secure gear placement. Spur gears were mounted on standardized steel shafts with press-fit tolerances, ensuring minimal backlash and consistent meshing.

To preserve the integrity of the setup, all shafts were lubricated with light machine oil, and axial alignment was checked using digital calipers and alignment gauges. Proper tooth engagement was verified by rotating the shafts manually before reassembling the gear housing.

Figure 4 shows the 3D model of the dedicated test module in which the gear pair with a transmission ratio of 1.04 is installed. The model represents a simple and functional configuration designed specifically for laboratory testing. In addition to the gears, the main components of this assembly include a housing made from a standard box profile, which serves as the structural support for all other parts.

The gears are mounted on steel shafts, connected using key joints to ensure reliable torque transmission without slippage. The shafts are supported by bearings designated as UCLF 202 and UCLF 204, which are fitted into the side walls of the housing and allow stable rotation with minimal friction. This configuration enables accurate simulation of real working conditions and reliable measurement of the mechanical efficiency of the gear assembly.

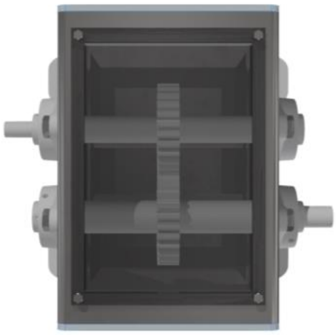

Fig. 4. 3D model of the dedicated gearbox module with a gear ratio of 1.04 – top view

Figure 5 shows the side view of the same test module, where the feet on which the entire structure is mounted are also visible. These feet provide elevation and structural stability to the gearbox housing, ensuring secure placement and proper alignment within the testing setup.

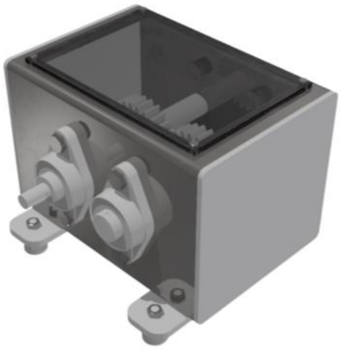

Fig. 5. 3D model of the dedicated gearbox module with a gear ratio of 1.04 – side view

This configuration follows the same structural concept as previously described, with laser-cut spur gears mounted onto precision-aligned shafts using key connections. The module maintains the standardized housing design and provides the same mounting interface for repeatable and comparable testing under identical boundary conditions (Figure 6).

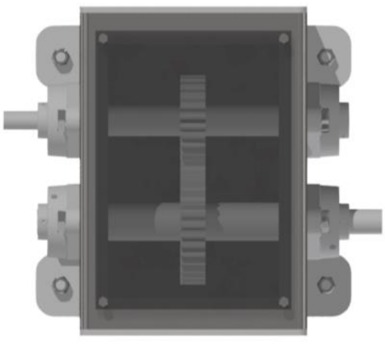

Fig. 6. 3D model of the dedicated gearbox module with a gear ratio of 1.23 – top view

In variation shown in Figure 7, the gear pair features a larger driven gear, increasing the transmission ratio while preserving the center distance. The spatial arrangement within the box-profile housing remains unchanged, ensuring that all gear pairs are tested under geometrically consistent setups. Lubrication and alignment procedures were carried out identically for all modules.

Fig. 7. 3D model of the dedicated gearbox module with a gear ratio of 1.23 – side view

Top view of the test module containing the gear pair with a transmission ratio of 1.42. This model demonstrates the effect of increased transmission ratio on gear size and tooth count while maintaining the same 80 mm center distance. All dimensional adjustments were made exclusively through the gear geometry, without altering the housing or shaft positions (Figure 8).

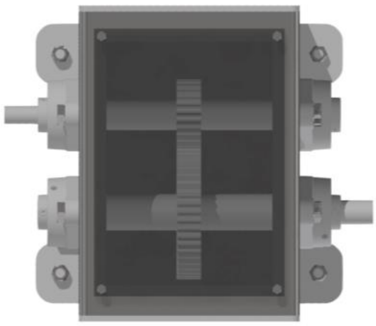

Fig. 8. 3D model of the dedicated gearbox module with a gear ratio of 1.42 – top view

Side view of the test module with the gear pair of ratio 1.42, mounted on structural feet. As in previous configurations, the module rests on robust steel feet, providing a stable base during testing. This side perspective highlights the spatial distribution of components within the housing and confirms the compact, modular design intended for rapid assembly and disassembly during experimental procedures (Figure 9).

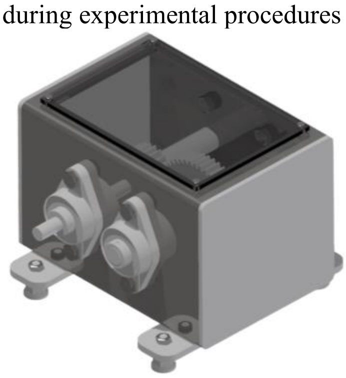

Fig. 9. 3D model of the dedicated gearbox module with a gear ratio of 1.42 – side view

Figure 10 shows the technical drawing of the assembled test model. The top part of the image presents the front view of the housing with the visible shaft positions and mounting elements.

Below, the sectional view A–A clearly displays the internal configuration, including the placement of shafts, gears, and the housing walls. This drawing was provided to illustrate the internal structure of the gearbox and ensure dimensional accuracy during assembly. It also serves as a reference for verifying alignment, spacing, and mechanical compatibility between components.

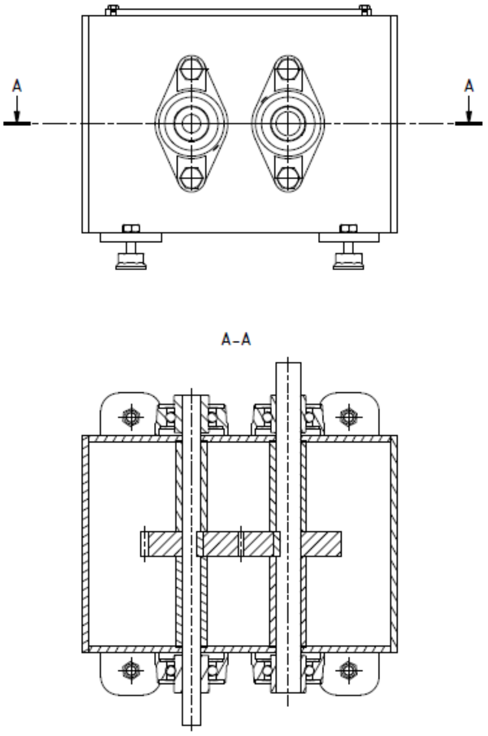

Fig. 10. Technical drawing of the test gearbox – front view and section A–A.

4.2 Test Environment and Measurement Setup

The GUNT AT200 system is equipped with an electromagnetic brake and a precision torque sensor to enable controlled loading of the gearbox. The test rig records input torque, output torque, and angular speed of both shafts. These parameters allow for direct calculation of mechanical efficiency:

$$\eta = \frac{T_{out} \cdot \omega_{out}}{T_{in} \cdot \omega_{in}} \times 100\% \quad (1)$$

where T represents torque and ω angular velocity:

- T_{in} - is the input torque,
- T_{out} - is the output torque,
- ω_{in} - is the angular velocity of the input shaft,
- ω_{out} - is the angular velocity of the output shaft

The GUNT AT200 test rig is equipped with an electromagnetic brake and high-precision torque sensors, enabling accurate measurement of input and output torque, as well as rotational speed. These values are continuously recorded throughout testing to enable real-time efficiency calculations.

Prior to each test sequence, the system was calibrated to ensure reliable data acquisition. Environmental parameters such as ambient temperature and humidity were also monitored, as they may influence frictional losses and sensor stability. All tests were conducted under comparable environmental conditions to ensure consistency and data validity across gear pairs.

Before the experiments, the apparatus was calibrated to ensure accurate measurements. Temperature and ambient humidity were logged, as they can influence friction and measurement stability. Each gearbox was tested under similar environmental conditions to ensure comparability of the results.

4.3 Experimental Plan

The experimental campaign consists of six gear pairs, all having an identical center distance of 80 mm, but varying transmission ratios from 1.00 to 1.96, as presented in Chapter 2. The test plan is structured as follows:

- Each gear pair is tested individually.
- Measurements are taken under three different load conditions to evaluate the load-dependence of efficiency.
- For each load condition, the test is repeated three times to ensure result consistency and reduce statistical deviation.
- The sequence of tests follows increasing gear ratios to observe efficiency trends with higher transmission ratios.

Data from the torque sensors is recorded using the GUNT software interface and exported for further analysis. All results will be compared to evaluate the effect of gear size, module, and ratio on overall system efficiency.

5. CONCLUSION

This study presented the preparation and initial methodology for testing the efficiency of laser-cut spur gears using the GUNT AT200 apparatus. Spur gears remain a widely used mechanical component, and this research aims to contribute to the cost-effective and rapid production of gears using modern laser-cutting techniques.

A total of six gear pairs were designed with varying transmission ratios, yet all maintained a constant center distance of 80 mm. CAD modeling was carried out using Autodesk Inventor 2019, employing the *Export Tooth Shape* function to ensure accurate involute profiles. The gear blanks were produced via laser cutting on a BODOR C6-12kW machine, with carefully selected cutting parameters and post-processing procedures to ensure surface quality and dimensional accuracy.

Test assemblies were prepared in accordance with the GUNT AT200 configuration, which allows precise measurement of torque and speed to evaluate mechanical efficiency. The experimental setup includes consistent measurement conditions, repeated load scenarios, and a structured testing plan to ensure result reliability.

Future work will involve conducting all planned tests and analyzing the efficiency trends in relation to gear geometry and transmission ratio.

The final goal is to determine whether laser-cut gears, prepared using simplified manufacturing processes, can offer acceptable performance levels in practical applications—especially for prototyping, educational use, or light-duty mechanical systems.

This study lays a solid foundation for further investigation into the mechanical performance and application scope of laser-cut gears.

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