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# ROZWIĄZANIA KONSTRUKCYJNE KOŁA WALCOWEGO O DUŻYCH WYMIARACH

**Streszczenie:** W dzisiejszych czasach, istnieją potrzeby zwiększenia parametrów pracy maszyn przy równoczesnej redukcji masy urządzeń. Duże przekładnie charakteryzują się tym, iż mają różne kształty obudowy przekładni oraz jej wewnętrznych elementów np. kół zębatych. Ma to istotny wpływ na parametry przełożenia. Jednym z kryteriów do oceny właściwej pracy koła zębatego o danej postaci konstrukcyjnej (kształcie) jest sztywność zazębienia oraz ciężar samego koła/kół. Artykuł jest poświęcony problemom projektowania optymalnego kształtu kół walcowych o dużych wymiarach. Możliwe procesy wytwarzania takich wielkich kół walcowych są następujące: odkuwanie, odlewanie, a nawet spawanie. Odpowiedniość proponowanego kształtu koła została oceniona poprzez zbadanie deformacji/odkształceń tego koła oraz analizując redukcję jego ciężaru. Zagadnienie rozwiązano dla wybranych kół walcowych.

**Słowa kluczowe:** projekt, kształt, koła stożkowe, MES, masa, sztywność zazębienia

# STRUCTURAL SOLUTIONS OF THE SHAPE OF SPUR GEAR WHEEL BODIES OF LARGER DIMENSIONS

**Summary:** Nowadays, there are demands for increasing the performance parameters of machines while reducing the weight of the equipment. Large gears are characterized by different shapes of gear bodies. This has a significant impact on the gearing parameters. One of the criteria for assessing the suitability of a gear body shape is the stiffness and strength of the gearing as well as the weight of the gear wheel itself. The paper is dedicated to the issue of designing the optimum body shape of spur gears of larger dimensions. The manufacturing process for the production of such spur gears can be forging, casting, or even welding. The

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suitability of the proposed shape was assessed on the basis of the deformation of the gearing and the weight loss of the gear body. The issue is solved for spur gears.

**Keywords:** design, shape, spur gears, FEM, mass, meshing stiffness

## 1. Introduction

When designing as well as optimizing the shape of gear bodies, whether using topology optimization or generative design, it is important to remember that none of the changes made must affect the mechanical properties of the gearing to any great or small extent. Namely the stiffness, which is of course corelated to the deformation.
The optimization process starts from a geometrically simpler solid body, where it is easy to define the individual parameters of the elements that will be used to fill the optimized space. These elements can be uniformly distributed in the given space.
Wang's work focused on gear volume reduction using Matlab software. Simulations in this software succeeded in reducing the volume by 25.2%, while the performance loss was 11.42% in the optimized gear [1]. Heiselbetz et al. focused on the optimization of the gear mass, taking into account the symmetry of the gear and the manufacturing process. The study consisted of a full profile of the gear, which was then recalculated via FEA and the locations which were least loaded were subsequently removed. Then, the given shape was modified to simplify the manufacturing process. The final gear shape had a reduced volume of 25% compared to the full profile [2,3]. The work of Xu Jin et al. was devoted to the design of a ball mill gear. The given wheel was designed for a smaller radius than the original wheel, but the design consisted of a lightened wheel where the shape of the web under the gearing was T-profile. The fixing of the wheel was designed through bolts in the given T-profile and the bolt locations were reinforced with a thicker wall [4,5]. Naveen et al. focused on thin-walled structures of gear wheel bodies. Experiment was carried out by creating three gear wheels differing in web thickness and placement, symmetrical thick web, asymmetrical thin web, and symmetrical thin web. In that study, the thin-walled profile had worse results than the thick-walled profile, especially the asymmetrically stacked web [6,7]. Marunic focused on the analysis of thin-walled asymmetric gears. As a result of this study, it was concluded that in case of thin rim under the gearing, maximum stresses are generated at the junction of the web with the rim. This location was confirmed for maximum stresses even when the thickness of the rack was changed while maintaining the dimensions of the rim. However, when a thicker rim was used, the maximum stress was also dependent on the thickness of the web. Thinner the web, higher the concentrated stress [8,9]. Zhao et al. performed shape optimization of a double-web arrow gear wheel. The wheel was optimized by adding material to the webs, i.e., increasing the thickness, and last but not least by changing the angle of these webs. Although the volume of the gear was increased by 5.3%, the maximum tension was reduced by 11.9% [10].

## 2. Shapes of gear bodies depending on the production of the semi-finished product

Smaller dimension gears can be conveniently made as welded gears. The wheels have the shape of a disc. Hub extension is achieved by welding a ring to the disc or by inserting a tubular hub into the disc bore (Fig. 1).

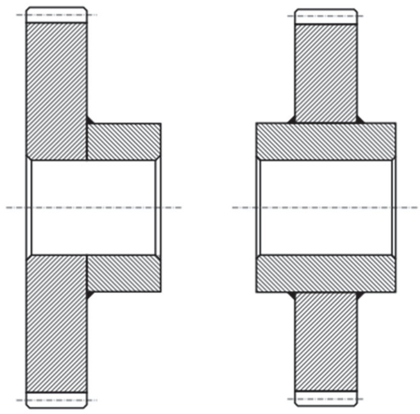
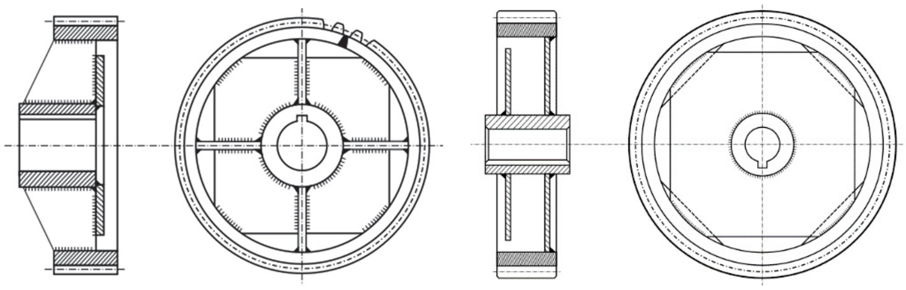


*Figure 1. Welded gears of smaller dimensions*

The larger welded gears have flat steel rims. The rim is connected to the hub either by one square plate and ribs (Fig. 2-a) or by two square plates (Fig. 2-b). The hub, plate and ribs are made of well-weldable commonly used steels. The rim is made of steels with better mechanical properties.

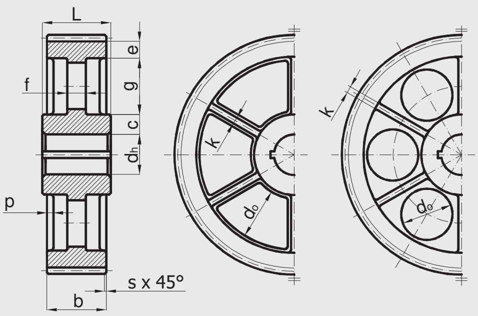


a) b)

*Figure 2. Welded gears of larger dimensions, a) - with plate and ribs, b) - with plates*

Casting is mostly used to create semi-finished products for large size gears. They are less load bearing than forged wheels. They are usually made of grey cast iron for circumferential speed $v < 7$ m.s$^{-1}$ and of steel cast iron for circumferential speed $v < 20$ m.s$^{-1}$. For spur gear diameters $d > 500$ mm the shape is given in Table 1.

*Table 1. Cast medium sized spur gear - basic geometric parameters*

<table>
<tr><th>Cast medium sized spur gear wheel</th><th>Gear parameters</th></tr>
<tr><td>
</td><td>$m_n$ – normalized modulus [mm]<br>h – height of key [mm]<br>b – gearing width [mm]<br>e = (4 to 5)$m_n$<br>c = (1.8 to 2.2)h<br>f = (0.2 to 0.3)b<br>$d_0$= (0.6 to 0.7)g<br>k=(0.4 to 0.6)f<br>p=(0.2 to 0.5)k<br>s = 0.3$m_n$<br>L=(1.0 to 1.25)b</td></tr>
</table>

Another way to make a larger spur gear is to use forging. This is used for head gear diameters smaller than 500 mm.

## 3. Practical demonstration of the gear body shape design procedure

The following fundamental gearing factors were created as a realistic example of the body shape optimization process: The gearing width coefficient is $\Psi=20$ , the number of teeth is z = 71, the normalized modulus value is m = 2.5 mm, the pressure angle is $\alpha = 20°$, the addendum coefficient is ha* = 1 and the clearance is ca* = 0.25. These criteria were developed in accordance with the practical need to create a gear body shape that would minimize the mass of the gear while preserving the strength of the gearing.

The mount hole on the body had to have a diameter of dh = 55mm, among other criteria. With a value of L = 60mm, the width of the gear hub needed to be bigger than the width of the gearing. Figure 3 depicts the gear's overall form at maximum weight, which functioned as a baseline for comparison with the suggested design adjustments to the gear body. The strength of the gearing of such a gear wheel is highest since the deformation of the gearing is smallest.

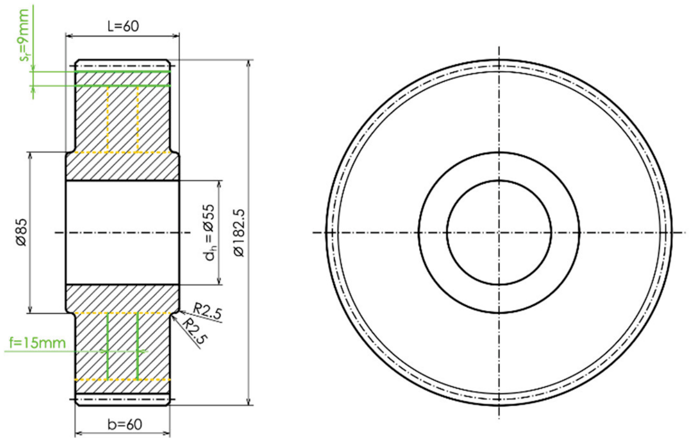
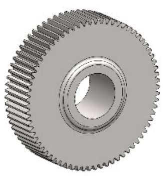
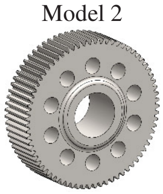


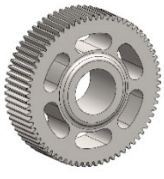

*Figure 3. Solid gear wheel shape with proposed body changes highlighted by green and yellow (MODEL 1)*

Five different body shapes have been proposed (Table 2). Comparison of the deformation values for each variant was in the first step compared with the solid body variant results. Later the variants were compared with each other for the purpose of finding the best proposed shape. The relieve hole variants functioned almost as well as the solid body variant for the values of the material analyzed above. The variants 3 and 5 had the lowest results, with version 5 having the greatest deformation value.

The best variant, according to the data above, was variant no. 2, and the poorest variant was number 5. The results for the remaining two variations, which fell between variants 2 and 5, were nearly identical.

*Table 2. Gear body optimization results for each variant*

| Image of the model with label | Total weight [kg] | Weight loss [%] | Deformation of the gearing in the middle of the width [mm] | |
|---|---|---|---|---|
| | | | Above the relieve element | Above the material |
| Model 1  | 8.929 | - | - | 0.00935 |
| Model 2  | 7.704 | 13.72 | 0.00986 | 0.00947 |

| | | | | |
|---|---|---|---|---|
| Model 3  | 6.790 | 23.96 | 0.01085 | 0.01002 |
| Model 4  | 4.719 | 47.15 | 0.01079 | 0.00962 |
| Model 5  | 4.445 | 50.22 | 0.01157 | 0.01068 |

## 4. Conclusion

Large gear wheel solutions are influenced by the requirements applied to them. One such requirement is the design of a gear with sufficient gearing stiffness and with the smallest possible body volume. Such a reduction in volume while maintaining stiffness means that the solution in question consists mainly of a change in the geometry of the wheel body.

Another possible requirement for gear shape solutions is to reduce production costs. This can be achieved by changing the dimensions of a given gear, the production machines used and, last but not least, the number of pieces of a given gear produced. Of course, the aim is to maintain the required stiffness of the gearing, therefore the knowledge obtained of the minimum dimensions of the various parts of the gear is able to speed up the process of solving the given design solutions.

The best weight reduction resulted from the suggested models/variants 4 and 5. However, out of all the suggested models, version 5 yielded the poorest deformation outcomes. Variant 4 had good results for gearing deformation as well as weight reduction that was compared to the best variant. Models 2 and 3 showed insufficient weight reductions while having relatively modest deformation results (compared to the lowest value). Given the weight loss Percentages and deformation values, model 4 would result in the best-performing optimization when these considerations are taken into account. This publication will form the basis for further optimizations, analyses, and software generation of body geometries in further studies.

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## REFERENCES

1. WANG C.: High power density design for planetary gear transmission system. Journal of Mechanical Engineering Science, **233** (2019), pp 5647-5658.
2. MEDVECKÁ-BEŇOVÁ S.: Influence of material and gear parameters on the safety of gearing in metallurgical industry. Metalurgija, **54** (2015), 224–226.
3. HEISELBETZ U., MÜLLER J.: Weight Optimization of a Gear Wheel Considering the Manufacturing Process and Cyclic Symmetry. Stuttgart International Symposium, (2009).
4. XU J., WANG C.: Small Module Design of Ball Mill Main Drive Gear with Φ2.4×10m. Advanced Materials Research, **787** (2013), 490-494.
5. MALÁKOVÁ S.: Kinematic properties and mesching condition of elliptical gear train. Sci. J. Silesian Univ. Technol. Transp., **104** (2019), 95–105.
6. CZECH P.: Autonomous vehicles: basic issues. Sci. J. Silesian Univ. Technol. Ser. Transp., **100** (2018), 15–22.
7. NAVEEN P. N. E., KUMAR B., GORIPARTHI B., HOTA R., MAYEE M., RAJU S. S. S. V.: Design and analysis of thin wall gear structure with Tio2/GF reinforced Nylon66 composites. Materials Today, **46** (2020).
8. MARUNIĆ G.: Rim Stress Analysis of Thin-Rimmed Gear. Key Engineering. (2007).
9. SAPIETKOVÁ A.: Simplified computation methodology for contact forces on tapered rolling bearing with flexible parts. Sci. J. Silesian Univ. Technol. Ser. Transp., **99** (2018), 177–182.
10. ZHAO N., SUN L., FU B., LI H., WANG Q.: Web Structural Optimization of the Big Aviation Herringbone Gear Based on APDL Language. Applied Mechanics and Materials, **487** (2014), 692-698.
11. WOJNAR G., CZECH P., FOLEGA P.: Problem with diagnosing local faults of gearboxes on the bassic of vibration signal. Transactions of the Universities of Košice, **2** (2014), 95-100.