

PROGRAM FOR CALCULATION OF WORM GEARING SYSTEM

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The aim of the paper is to point out to a possibility of program creation which would facilitate calculation of geometric dimensions of worm gearing system for students at secondary technical schools and universities as well as for employees working in the technical field with the following parameters: module, number of worm teeth, gear ratio, and coefficient of worm diameter. The paper contains detailed description of procedure of calculation of worm gearing system and of a created program in the programming language of Java. The programming environment of NetBeans and the library of graphic components of Swing were used in creation of the program. The final program version also contains the possibility of calculation of a module according to the standard and analysis of forces acting upon worm wheel.

KEYWORDS

program, worm, worm gear

1 INTRODUCTION

Worm gearing system is in fact cylindrical screw gearing system in case of which number of teeth of a driving wheel (of a worm) amounts to $z_1 = 1, 2, 3$, and in exceptional cases the value is even higher. A mating wheel is referred to as a worm wheel. A worm and a worm wheel create together a worm gearing system serving for transmission of rotation motion and of torques frequently to mutually perpendicular skew shafts. The worm and the worm gear can be cylindrical or globoid. In practice for transmission of low and of average performance is mostly used worm gearing system with a cylindrical worm and a globoid wheel. The worm tooth profile is mostly linear and trapezoidal – the worm with a conventional gearing system or with linear axial profile (Archimedes screw) [Maščenik 2017a].

2 WORM GEARING SYSTEM

2.1. Proposal of Calculation Procedure

a) With given “P1”, “n1”, “u” and technical service life of the gear “Lh” the calculation procedure can be divided as follows:

1. Selection of number of teeth z_1 , selection of toothing type (ZN, ZA, ZI) and preliminary selection of material; calculation of $z_2 = z_1 \cdot u$. In case of good required effectiveness a higher number of worm teeth z_1 is selected which, however, causes increase of dimensions of the gear; according to a requirement for self-locking the relation $\gamma \leq \phi'$ must be applicable between the lead angle of the worm γ and the friction angle ϕ' ; toothing ZA is suitable for small γ , for $z_1 = 1$ and 2, for unhardened and rough worm it has a more universal use. In case of selection of teeth it is inevitable to check if undercutting occurs, otherwise correction by a profile shift would be necessary.

2. Preliminary calculation of diameter d_2 and determination of module m_x which is adjusted to a standardized value in case of the ZA toothing; in case of the conventional toothing the module

m_n is determined which is adjusted to the standardized one; angle γ shall be estimated preliminarily in dependence on the number of teeth in Table 3 provided that it has not been specified by the requirement for self-locking.

3. Geometric calculation of the worm, of the worm wheel, and of the axial distance; drawing of a dimensioned sketch.

4. Calculation of effectiveness.

5. Strength checks of toothing for contact strain, for bending and check of heat output.

6. Solving of force relations in the toothing and calculation of reactions in the shafts.

7. Check of strength and stiffness of shafts, design proposal of shafts and other inevitable calculations.

b) In case that axial distance is prescribed as an extra, the following procedure can be recommended:

1. If z_1 is selected, the dimension of the given axial distance must be taken into consideration.

2. Preliminary geometric calculation of diameters d_2 and d_{w1} according to the following:

$$a_w = \frac{1}{2}(d_{w1} + d_2), \quad u = \frac{d_2}{d_{w1} \operatorname{tg} \gamma_w} \quad (1)$$

3. When preliminary selection of angle γ_w has been carried out, d_2 and d_w shall be calculated on the basis of both equations.

4. Check of teeth contact strain for the wheel with diameter of d_2 and with width of $b_2 = \Psi_d \cdot d_{w1}$; in order to have the diameter d_2 satisfactory, it must be adjusted by an adequate material selection.

5. Determination of the module m_x or m_n .

6. Determination of coefficient of worm diameter q and of coefficient of shift of the x profile so that prescribed axial distance is achieved; q should be corresponding with recommended values and with regards to threat of root undercutting and to threat of teeth sharpness x should not deviate from the range of $x = \pm 0.7$. To meet the equation a small change of number of teeth might sometimes be helpful unless gear ratio z_2/z_1 differs from the given gear number more than tolerance permits.

7. Geometric calculation of the worm and of the worm wheel; drawing of a dimensioned sketch. Further procedure follows the previous task [Maščenik 2017b].

2.1.1. Selection of Parameters and Calculation of Geometric Dimensions of Cylindrical Worm Gear

2.1.1.1. Design Proposal of Module of Worm Gearing System

Design proposal of module size and consequent preliminary dimensioned calculation and strength check of the worm gearing system can be carried out on the basis of design calculation of the module:

a) stemming from a limiting condition of contact strain. Module size can be determined according to the following equations:

- for steel worm and tin bronze:

$$m_n \cong 7900 \sqrt[3]{\frac{M_{k1} \eta \left(1 - \left(\frac{z_1}{q}\right)^2\right)^2}{z_1 z_2 q \sigma_{Hc}^2 \sqrt{\frac{N_0}{N_E}}}} \quad [m], \quad (2)$$

- for steel worm and aluminium bronze:

$$m_n \cong 7100 \sqrt[3]{\frac{M_{k1} \eta \left(1 - \left(\frac{z_1}{q}\right)^2\right)^2}{z_1 z_2 q \sigma_{HD}^2}} \quad [\text{m}], \quad (3)$$

- b) according to the Bach equation in case of which normal module of toothing m_n is calculated as follows:

$$m_n \geq \sqrt[3]{\frac{2 \cdot M_{k1} \cdot \eta_z}{\pi \cdot c \cdot \psi_m \cdot z_1}} \quad [\text{mm}] \quad (4)$$

$$\psi_m = \frac{b_n}{m_n} \quad (5)$$

ψ_m is selected: $\psi_m = 8$ up to 12

Determined module of toothing shall be rounded to the standardized one and dimensions of gearing system shall be specified. Selection of material pair of the gearing system follows the sliding speed. If no detailed information on parameters and material of the gearing system is provided, the module as per Bach shall be selected (the aforementioned point b)). In case of well-known information and material pair the module according to the aforementioned point a) shall be selected [Maščenik 2017b, Pavlenko 2017a].

Table 1. Modules of the worm gearing m

Order 1	1	1,25	1,6	2	2,5	3,15	4	5	6,3	8	10	12,5	16	20	25
Order 2	-	1,12	1,4	1,8	2,24	2,8	3,55	4,5	5,6	7,1	9	11,2	14	18	22,4

Preferred is order 1.

2.1.1.2. Materials of Toothing of Worm Gears

Materials of friction pair in the gearing system should have the following: positive friction properties, appropriate wear, resistance to seizure [Cacko 2014, Smeringaiova 2018a,b]. Dominant material for worms is steel, i.e. carbon steel or alloy steel which through heat treatment allows production of hard surfaces; hardening to HRC 45 up to 50, case-hardening and hardening to HRC 56 up to 62 or nitriding – 56 HRC. Teeth flanks are then ground and may be possibly polished. Steel worms in the heat-treated or standardly annealed condition are used only in case of lower performance and in case of low sliding speed v_k .

Materials of Worm Wheels (Toothing)

Basic material for worm wheels is bronze and less frequent are cast iron or brass. Wheels made of plastic material can be used in case of low performance; they absorb shocks well and reduce noisiness [Murcinkova 2013]. In case of bronze use the wheels are designed as the combined ones due to economic reasons. Bronze rim is mounted and adequately fixed on the cast-iron or steel body of the wheel. A high-quality semi-product of the rim is gained by means of centrifugal casting.

Appropriate material of the rim is tin bronze with high tin content (10 up to 12%) with excellent friction properties resistant to seizure. At the same time tin bronze is good at running in procedure. This type of material is intended for exposed gears and for sliding speed $v_k > 10$ m/s. However, in this case an effort to replace it by other material is made, for

instance, by nickel tin bronze. In case of speed $v_k = (4$ up to 10) m/s bronze with lower tin content can be used (5 up to 6%). [3]

Cheaper bronze variants without added tin such as aluminium bronze or lead bronze or brass are suitable for speed of $v_k < 4$ m/s. They are rather hard and strong yet not that resistant to seizure and not that good at running in procedure. Therefore the mating wheel must have rather hard surface, at least HRC 45. In case of bronze use with $R_m > 400$ and with $v_k > 1$ m/s the hardened or nitrided wheels are recommended. In case of gearing system with a large worm wheel a combination of worm made of bronze and cast-iron wheel can be used due to economic reasons.

The wheel made of grey cast iron in a pair with the steel worm is suitable for gears subjected to less intense strain and for $v_k < (1.5$ up to 2) m/s.

Preliminarily the hypothetical value of sliding speed in the worm gearing system can be determined on the basis of the following equation:

$$v_K \cong 4,5 \cdot 10^{-4} n_1 \sqrt[3]{M_{k2}} \quad [\text{m/s}] \quad (6)$$

Materials of worm wheels can be selected in relation to v_k as follows:

- tin bronze for $v_k > 10$ m/s,
- tin lead bronze for $v_k = (4$ up to 10) m/s,
- aluminium bronze for $v_k < 4$ m/s,
- brass for $v_k < 4$ m/s,
- grey cast iron for $v_k < 2$ m/s.

Table 2. σ_{HD} [MPa] with regards to seizure

Material of worm wheel		v_k [m/s]				
		0,5	1	2	3	4
Aluminium bronze	Cu Al9 Fe3	189	179	173	167	160
	Cu Al10 Fe4 Ni4	195	192	187	181	175
Brass	Cu66 Al6 Fe3 Mn2	172	169	154	149	141
	Cu58 Mn2 Pb2	120	118	112	106	100
Grey cast iron	42 2415	130	115	85	-	-
	42 2418					
	42 2424	150	130	100	-	-
	42 2428					

2.1.1.3. Effectiveness of Cylindrical Worm Gear

Effectiveness of cylindrical worm gear can be estimated for the first design proposal of the gear according to table 3.

Table 3. Effectiveness of worm gear

$z1$	1	2	3	4
η	0,70 ÷ 0,75	0,75 ÷ 0,82	0,82 ÷ 0,87	0,87 ÷ 0,92
γ	≈ 6°	≈ 11°	≈ 16°	≈ 22°

More precise value of effectiveness of the gearing system shall be determined according to the model as follows:

$$\eta_z = \frac{\text{tg} \gamma}{\text{tg}(\gamma + \phi')}, \quad (7)$$

with

ϕ' refers to friction angle in the toothing which depends on friction material pair, surface quality, and sliding speed. [3]

For the most common material pair the following is applicable: for the heat-treated steel worm and brass rim of the wheel the f' can be determined according to the figure (Fig. 1) [Pavlenko 2017b].

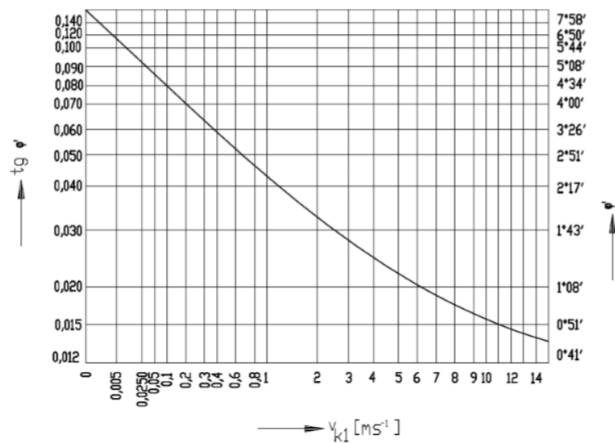


Figure 1. Friction angle φ' depending on sliding speed v_{k1}

Coefficient of friction in the toothings:

$$f' = tg\varphi' \quad (8)$$

For material pair: steel worm and wheel made of grey cast iron:
 $f' = 0.06$ up to 0.12 .

Effectiveness of shafts in the gear:

$\eta_i = 0.995$ for ball bearings,

$\eta_i = 0.99$ for roller and tapered roller bearings.

Effectiveness in case of toothed wheels wading in the oil bath:

$$\eta_b = 1 - \frac{vb\sqrt{v\gamma}}{10^6 P} \quad (9)$$

2.2. Dimensional Calculation of Worm Gear

2.2.1. Models for Calculation of Geometric Dimensions of Worm

The dimensions of the previous cases are applicable for the table of data. Basic models for calculation of geometric parameters of worm gearing system are given in table 4.

Table 4. Table of models

Quantity name	Worm	Wheel
Number of teeth	z_1	$z_2 = i \times z_1$
Normal module of toothings	m	
Axial module	$m_x = \frac{m}{\cos\gamma}$	
Pitch of teeth	$p_n = \pi \times m_n$	$p_x = \pi \times m_x$
Standardized parameters	$\alpha = 20^\circ, h_a^* = 1, c_a^* = 0.2$	
Lead angle	$tg\gamma = \frac{z_2 \times m}{d_1}$	
Height of tooth head	$h_a = m$	
Height of tooth root	$h_f = 1.2 \times m$	
Diameter of pitch circle	$d_1 = q \times m_x$	$d_2 = z_2 \times m_x$
Coefficient of worm diameter	$q = \frac{z_1}{tg\gamma} = \frac{d_1}{m_x}$	
Axial distance	$a = 0.5(d_1 + d_2)$	
Lead angle	$\gamma = \arctg \frac{z_1}{q}$	
Diameter of head circle	$d_{a1} = d_1 + 2 \times h_a$	$d_{a2} = d_2 + 2 \times h_a$
Diameter of root circle	$d_{f1} = d_1 - 2 \times h_f$	$d_{f2} = d_2 - 2 \times h_f$
The largest diameter of head cylinder of the wheel	<p>pri $z_1 = 1 \text{ až } 3; d_{aH2} = d_2 + 1.5 \times m$</p> <p>pri $z_1 \geq 4; d_{aH2} = d_2 + m$</p>	
Width of the wheel toothings	<p>pri $z_1 = 1 \text{ až } 3; b_2 \approx 0.75 \times \left(1 - \frac{2}{q}\right) \times d_1$</p> <p>pri $z_1 \geq 4; b_2 \approx 0.67 \times \left(1 - \frac{2}{q}\right) \times d_1$</p>	
Radius of undercutting of the head area	$R = \frac{d_1}{2} - h_a$	

Table 5. Coefficient of worm diameter q [7]

m [mm]	2	2,5	3,15	4	5	6,3	8	10	12,5	16
q	16	12,5	12,5	10	10	10	9	8	8	8
		14	14	12,5	12,5	12,5	10	10	10	8
				14	14	14	12,5			

For $z_1 = 1$ selected should be 12,5 q , for $z_1 = 4$ selected should be 8 q [Pavlenko 2017].

3 PROGRAMMING LANGUAGE OF JAVA

The programming language of Java represents higher programming language which can be characterized as follows:

- Simple.
- Independent from architecture.
- Object oriented.
- Portable.
- Distributed.
- Highly efficient.
- Multi-fibre.
- Robust.
- Dynamic.
- Safe [12]

In the programming language of Java the entire source code is firstly written as a simple text into files with the suffix of .java. These source files are consequently compiled into the files with the suffix of .class by means of javac compiler. The file with the suffix of .class does not contain the code which could be processed by the processor; instead it contains bitecodes for a virtual computer Java Virtual Machine1 (Java VM – virtual computer). The triggering tools of java shall activate the application along with the virtual computer Java Virtual Machine [Pavlenko 2017].

3.1. Java Platform

The platform represents hardware or software environment in which the programs are activated. The most common are platforms such as Microsoft Windows, Linux, Solaris OS and Mac OS. Majority of platforms is a combination of operating system and pertaining hardware. The Java platform is different as it represents sheer software platform running over other hardware based platforms.

The Java platform consists of two components as follows:

- Java Virtual Machine
- Java application programming interface (API)

The component of Java Virtual Machine is the basic component of the Java platform and is implemented into several hardware based platforms.

API represents a collection of software components for development of applications which offers a number of useful functions grouped in libraries or related classes and interfaces. These libraries are known as packages.

API and Java Virtual Machine isolate the program from the basic hardware.

As the platform independent environment the Java platform can be slightly slower contrary to the program having been compiled for a particular hardware (native code). However, advantage of the compiler and of the virtual computer technology rests in approximation to performance of the native code without loss of portability to other hardware platforms.

Terms of "Java Virtual Machine" and "JVM" refer to virtual computer for the Java Platform.

3.2. Use of the JAVA Programming Language

The main aim of the aforementioned programming language of Java is strong software platform. Each fully implemented Java platform offers the following advantages:

Development tools: Development tools offer anything that is needed for compilation, activation, monitoring, debugging and documentation of applications. The most frequently used tools are as follows: javac compiler, java loader, javadoc tool for creation of documents.

Application Programming Interface (API): API offers basic functions of the Java programming language. The environment offers a number of useful classes ready to be applied. They contain anything from the basic objects through network and security up to XML generation (Extensible Markup Language) and access to databases, etc. The API core is rather extensive. More detailed overview of its content is presented in documentation of Java SE development Kit 8 (JDK – java development tools).

Development Technologies: JDK software offers standard mechanisms such as Java Web Start and JavaPlug-In Software in order to allow triggering of applications by the final user.

Tools of User Interface: Swing and Java 2D tools allow creation of sophisticated graphical user interface (GUI).

Integrable Libraries: Integrable libraries such as Java IDL API, JDBC API, java name and address services ("J.N.D.I.") API, remote method invocation (Java RMI) and remote method invocation via Inter-ORB protocol (Java RMI-IIOP Technology) allow access to databases and manipulation with remote objects.

4 NETBEANS

NetBeans is a successful Open Source project with rather extensive user basis and increasing community of developers.

Two main types of the NetBeans products exist:

- integrated development environment NetBeans (NetBeans IDE),
- development platform of NetBeans (The NetBeans Platform).

4.1. NetBeans IDE

Development environment of NetBeans IDE is a tool by means of which programmers can create, translate, and debug the applications. The development environment is created in the Java language – yet it can support any programming language. Apart from the aforementioned there exist many modules which spread this development environment. The development environment of NetBeans is a product being spread free of cost which can be used without limits.

4.2. NetBeans Platform

Apart from the development environment there is also other platform available – NetBeans Platform which represents a modular and spreadable basis for creation of extensive applications. Independent software suppliers offer modules for integration into the platform. The modules serve for development of their own tools and solutions.

4.3. Licensing

Both products are developed under the license of Open Source and they can be used free of cost both in commercial and non-commercial environment. The source code is available under the license of Common Development and Distribution License (CDDL).

5 DESIGNED PROGRAM

The program is divided into 3 main parts:

- module calculation,
- calculation of geometric dimensions,
- calculation of force ratio in the toothing.

5.1. Calculation of Module

In the introductory window the program offers possibility of module calculation. The following data are inevitable for the calculation:

- torque of the worm,
- efficiency of the worm gear,
- number of the worm teeth,
- coefficient of the worm diameter,
- gear ratio.

Other data are entered in dependence on selection of the calculation model:

The following is applicable for steel worm and tin bronze:

- Permitted limit of permanent fatigue strength
- Basic number of cycles
- Rotations of worm wheel
- Technical life of the gearing system

The following is applicable for the steel worm and aluminium bronze:

- Permitted value of contact strain

If the button "Calculate" is pressed, the module is calculated and entered into the text field for the module by the program.

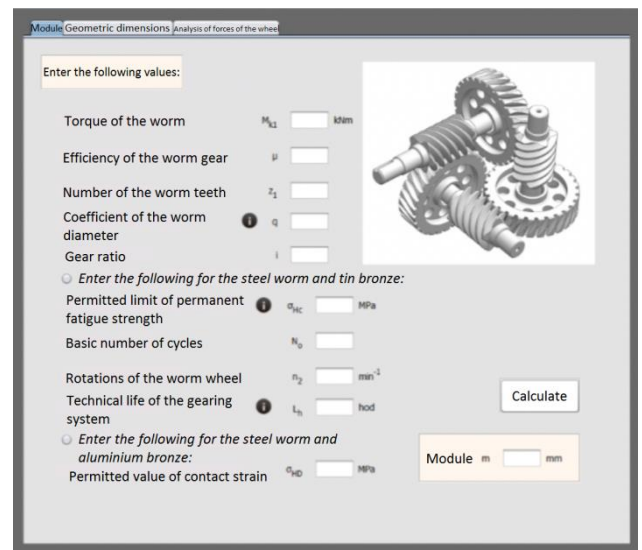


Figure 2. Demonstration window of the program

When clicking on the "i" icon in the black circle, the table shall open out of which the particular value is selected:

5.2. Calculation of Geometric Dimensions

If a user uses the introductory tab for the module calculation, all of the values inevitable for the calculation shall be entered automatically. If the user skips the aforementioned step, they must be filled in manually. When the button "calculate" is pressed, all of the geometric dimensions of the worm gear and of the worm shall be calculated and entered into the respective text fields by the program.

5.3. Calculation of Force Ratio in the Toothing

In case that a user follows all of the aforementioned steps, all values shall be filled in except for friction angle. To detect magnitude of friction angle it is possible to use an assistant in the "i" shape which shall activate a dialogue window. If button

“calculate” is pressed, all of the forces shall be calculated and entered into text fields by the program [Bičejová 2017a,b].

European Alliance for Innovation, 2018, pp. 1-8. ISBN 978-1-63190-167-6.

6 CONCLUSIONS

The paper pointed out to the possibility of creation of the application which shall facilitate calculation of the module, geometric dimensions, and forces acting in the worm gearing system. The aim of the application is to make the studying easier for the students at universities technically oriented as well as for those at secondary technical schools. The application can be employed in teaching of more subjects as a helping tool. The application can be also used in technically oriented companies.

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