UNIVERSITY OF NOVI SAD
FACULTY OF TECHNICAL SCIENCES
ADEKO - ASSOCIATION FOR DESIGN, ELEMENTS AND CONSTRUCTIONS

KOD
Konstruisanje • Oblikovanje • Dizajn
2008

PROCEEDINGS

5

THE 5TH INTERNATIONAL SYMPOSIUM ABOUT DESIGN IN MECHANICAL ENGINEERING

NOVI SAD, 15 - 16 APRIL 2008

NOVI SAD, 2008

The Fifth International Symposium

about forming and design in mechanical engineering

KOD 2008

PROCEEDINGS

Novi Sad, 15 – 16 April 2008

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Dear Ladies and Gentlemen, respectable Colleagues and Friends of KOD,

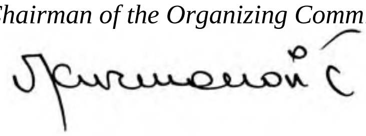
It is a real pleasure and great honor for me to greet You on behalf of the Organizing Committee of the fifth international symposium about forming and design in mechanical engineering – KOD 2008. This year, symposium KOD takes place at the Faculty of Technical Sciences in Novi Sad, Serbia on 15th and 16th April 2008, and I would like to thank You for participating in it.

As we all know, the basic goal of this event is to assemble experienced researchers and practitioners from universities, scientific institutes and different enterprises and organizations from this region. Also, it should initiate more intensive cooperation and exchanging of practical professional experiences in the field of shaping, forming and design in mechanical engineering. Having always present need for making more effective, simplier, smaller, easier, noiseless, cheaper and more beautiful and esthetic products that can easy be recycled and are not harmful for environment, the cooperation between specialists of these fields should certainly be intensived.

A hundred and three articles, by authors from ten countries, are published in this Proceedings. This is certainly significant number, which means these topics have potentials and are very interesting for researchings.

Thank You for coming in Novi Sad to take part in symposium KOD 2008 and for Your interesting articles. I wish You success in Your further researchings and great fortune and happiness in personal life.

Prof. PhD. Siniša Kuzmanović, Eng.
Chairman of the Organizing Committee of KOD



Novi Sad, 15 April 2008

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CONTENTS:

The 5th International Symposium
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AUTOMATIZATION OF RADIAL JOURNAL BEARINGS DESIGN PROCESS

Dragan MILČIĆ
Vojkan MILOŠEVIĆ
Miroslav MIJAJLOVIĆ

Abstract: *Calculation of radial hydrodynamical journal bearings is relatively complicated and requires great number of iterative solution steps in order to reach adequate solution. This is the reason why the software for calculation and modeling of radial hydrodynamical journal bearings has been developed. This software gives possibility to easily check maximal carrying load of journal bearings, hydrodynamical floating conditions and thermal stability issue – working temperature of bearing. This software connects calculation module to the CAD (Autodesk Inventor) where can get virtual model of standard journal bearings.*

1. INTRODUCTION

Product shaping is very important phase of design process. Shaping theory is scientific discipline which studies methods and acts of parts, machine assemblies and machines shaping. Shaping tools, hardware and software for visualization of shapes by computer applications are parts of shaping theory, also.

Application of computers in product shaping process includes Computer Aided (CA) technologies – Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), and Computer Aided Engineering (CAE). Software applications, used for shaping in this phase of design have to enable and ease:

- Static and dynamic calculations,
- Element modeling, including complex shapes and three dimensional (3D) curves or faces,
- Elements assembling into precisely defined relations and shapes,
- Application of standard elements, generated from adequate databases or part libraries (springs, bolts, bearings etc.),
- Automatic development of technical documentation as product of modeling and assembling,
- Automatic creation part lists,
- Simulation of movements and monitoring in working condition,
- CNC code generation, in order to automate manufacturing process,
- Sheet metal design support, mold base, for metals and plastics etc.,
- IGES i STEP database generation and usage in other CAD and CAM systems,
- Constructive optimization,
- Mechanism analysis,
- Analysis of experimental data derived from prototype testing,
- Marketing support – easy presentation making, realistic rendering, animation.

Virtual product development enables high speed innovations and manufacturing, high quality products and economic production.

Corporation's concurrence and quick accommodation to market requests require software for calculations of mechanical parts and tools which will enable easy 3D modeling and other automatization (CAD, CAD/CAM or CAD/CAM/CAE tools).

Faculty of Mechanical Engineering Nis is working long time period on development of integrated computer program for complete design of power transmitters – Power Transmitter Design Software (PTD). Integrated program system PTD, shown in Figure 1, has three main parts:

1. Program modules for power transmission element's calculation,
2. Program modules for calculation of rotation elements,
3. Program modules for calculations of mechanical connections.

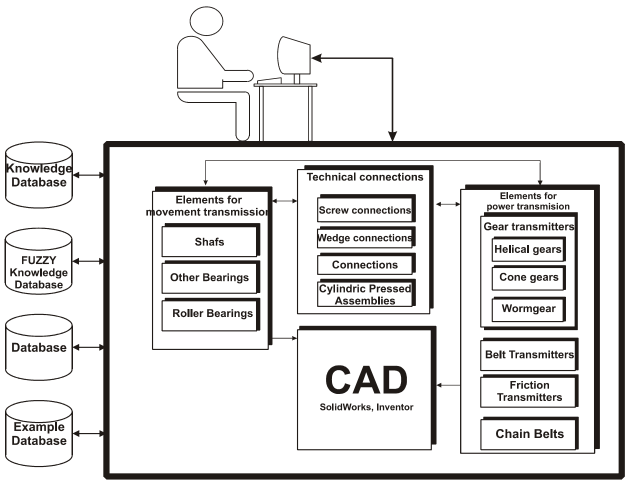

Fig. 1. Integrated system for power transmitters design PTD [9]

Integral part of program module, for rotation elements is software for calculation and design of radial hydrodynamical journal bearings. Software is capable to automate design process of these bearings. There is dynamical connection between this software and Autodesk Inventor Software (AI) – calculated and designed bearing and its components are automatically modeled in AI.

2. RADIAL JOURNAL BEARINGS DESIGN PROCESS

Modern knowledge and design science still do not include tribological aspects of design enough, even thou they are main condition of work without failures for moving parts (wearing). From tribological point of view, it is very important to make adequate selection of elements included in the system – machine. These aspects concern about material, lubrication and system of lubrication. After that, designer has to determine working and tribological characteristics of system – work rate in function of wearing, lubrication, temperature, friction etc.

Journal bearings are very often used in heavy machinery: for cranes, milling machines, turbines, choppers, rollers, presses, redactors etc. As its name says, journal bearings parts are journal one by another during work. Basic advantage of journal bearings, comparing to the roller bearings is in their carrying strength – working rate. If journal bearings have hydrodynamical floating conditions, bearing has almost infernal working rate. This is very important fact considering machines working with large rotating speed. In this situation, roller bearings are almost useless. On the other hand, modern machine design trend, requests increase of carrying load, velocity and round speed and decrease of mass. This trend shows that application of journal bearings is going to increase.

Because of the large area of contact between shaft and the tilting pad - grove (which always have to be separated by lubricant), journal bearings have ability to reduce noise and vibration – journal bearings can reduce severe working overloads during work. Journal bearings can be manufactured as single parted or as double parted. Roller bearings are always single parted. This is second main advantage of journal bearings – they can be used in situations where roller bearings cannot be used because the montage. Most familiar example of journal bearings usage is at crank shaft.

Single element and mass production price difference of journal bearings is significantly smaller then for roller bearings. Roller bearings are concurrent and economic to produce only for mass production. For shaft diameters, smaller than 10 mm and larger than 300 mm roller bearings are produced only for special cases what gives great advantage to usage of journal bearings.

Journal bearings are more compact and smaller than roller bearings. If we compare two bearings, journal and roller, with same carrying ability, journal bearing is much smaller than roller bearing. This is an advantage for usage on shafts, loaded with radial forces.

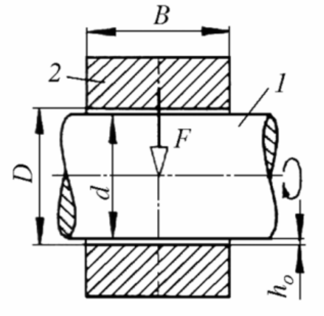

Fig. 2. Radial journal bearing

Figure 2 shows the most important part of the journal bearing – journal par: shaft (1) and tilting pad (2).

For easier comparison, main characteristics of journal and roller bearing are given in table 1

Table 1. Characteristics of roller and journal bearings

	Roller	Journal with hydrodynamical floating
Specific load	−	+
Dimensions	−	+
Work rate	−	+
Price	−	+

External loads on the journal bearings, expressed by force F, must be equally distributed over the complete journal area of journal pair. Because the relatively movement of the journal surfaces, friction as resistance to journal appears. Significant amount of mechanical energy is being converted to heat, what results in increase of working temperature. Under the circumstances wearing of the journal pair increase, dimensions and shape of journal pair change, also.

Best protection from wearing and significant decrease of friction is achieved when contact surfaces of journal pair are completely separated with lubricant – oil. Friction coefficient μ decreases, comparing to the static friction coefficient up to the 100 times and its values is μ=0,005÷0,001. This type of friction is called **liquid friction**. Layer of oil, between surfaces caries the same force F, so it is expectable to have significant pressure in oil film, in order to keep continuum and avoid direct contact of journal surfaces. With hydrodynamic lubricated bearings, oil film is being formed only if journal surfaces are moving one to each other. Journal velocity must be large enough and journal surfaces positioned at correct angle one to another in order to take oil into the bearing and keep adequate pressure in the oil film.

Hydrodynamical floating is an imperative for efficient usage of journal bearings during all projected working life. Oil film is carrying element; it is equivalent to the rollers, needles, spheres at roller bearings.

Prerequisite for successful creation of oil film is choice of oil adequate lubricant characteristics. Even in condition of liquid friction, there are significant resistances to journal. Resistances appear in the oil film itself, and it is measured as viscosity. Viscosity is ability of fluid to resist change of its shape and it is expressed by tangent stresses between layers of fluid which are moving one opposite to another. According to Newton's law, tangent stress in planes is equal:

$$\tau = \frac{F_t}{A} = \eta \cdot \frac{dv_k}{dy} \tag{1}$$

meaning, it is proportional to the gradient of velocity over perpendicular direction to the direction of movement. Coefficient of proportionality η is called dynamical viscosity and it is equal to:

$$\eta = \frac{\tau}{dv_k/dy} \tag{2}$$

Beside dynamical viscosity, there is kinematical viscosity ν, equal to de ration of dynamical viscosity η and oil densityρ:

$$\nu = \frac{\eta}{\rho} \tag{3}$$

Viscosity of liquid lubricants depends of temperature and pressure. Increase of temperature, decreases viscosity and increase of pressure, increases viscosity.

According to ISO viscosity classification, all liquid lubricants for industrial usage are separated according to middle value of kinematical viscosity at 40^0C in 18 groups: ISO VG 2, 3, 5, 7, 10, 15, 22, 32, 46, 68, 100, 150, 220, 320, 460, 680, 1000 and 1500. Number in definition of ISO VG mark, represent value of kinematical viscosity with variation of ±10%.

3. CALCULATION OF RADIAL JOURNAL BEARINGS

Calculation for journal bearings is an iterative process. For first iteration, some of the values have to be guessed, than recalculated and used as input for new iteration.

Carrying load represents maximal force that journal bearing can carry throughout its life span without overcoming allowed temperature, intensive wear out or surface destruction of journal bearing. If there is hydrodynamic lubrication, oil film should be greater than minimal allowed value.

List of symbols used in calculation.

p_{doz} -allowed surface pressure for chosen material
h_{omin} -allowed thickness of oil film
ω -angular velocity
μ -friction coefficient
ρ -oil density (ρ = 900 kg/m^3)
c -specific oil caloric, c = 2000 $J/(m^3K)$
q -oil flow m^3/s
υ_i -temperature of oil at the exit °C
υ_u -temperature of oil at the entrance °C
C_{gr} -constant (1÷8)

Calculation process follows the procedure:

3.1. Bearing dimensions:

d - diameter of the shaft
D - inner diameter of tilting pad
B - length of tilting pad

3.2. Design characteristic:

$$\varphi = B/D = 0{,}2...1...(1{,}5) \tag{4}$$

φ = 0,5÷1 – speedy, less loaded bearings
φ = 0,3÷0,7 – optimal value

3.3. Specific load of bearing:

$$p = \frac{F}{B \cdot D} \le p_{doz} \tag{5}$$

3.4. Absolute gap:

$$f = D - d \tag{6}$$

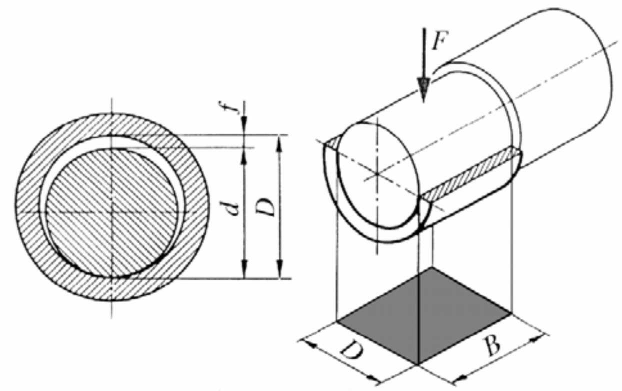

Figure 3. Specific load of radial journal bearing

3.5. Relative gap:

$$\psi = \frac{f}{D} = \frac{D-d}{D} \tag{7}$$
$$\psi = 0{,}8 \cdot \sqrt[4]{v}$$

Selected value for za ψ can be achieved with some following leanings *H7/a8*, *H7/b8*, *H7/c8*, *H7/d8*, *H7/e8*, *H6/f6*, *H7/f7*, *H5/g4*, *H5/g6*, *H7/g6*.

3.6. Journal velocity for minute rounding speed *n*

$$v = \frac{\pi \cdot d \cdot n}{60} \tag{8}$$

3.7. Minimal thickness of oil film:

$$h_0 = \frac{D \cdot \psi}{2}(1-\varepsilon) \ge h_{0min} \tag{9}$$

3.8. Relative thickness of oil film:

$$\delta = \frac{h_0}{f/2} = \frac{h_0}{\psi \cdot d/2} \tag{10}$$

3.9. Eccentricity:

$$e = \frac{f}{2} - h_0 \tag{11}$$

3.10. Relative eccentricity:

$$\varepsilon = \frac{e}{f/2} = 1 - \delta \tag{12}$$

3.11. Characteristic of bearings carrying ability (Somerfield's number):

$$S_0 = \frac{p \cdot \psi^2}{\eta \cdot \omega} \tag{13}$$

Somerfield's number enables to compare bearings about speed and carrying ability, so, it represents carrying ability. As function of Somerfield's number S_0, there are tri different types of journal bearings:

- $S_0 \le 1$ - speedy, less loaded bearings;
- $S_0 > 1 \div 3$ – medially loaded bearings;
- $S_0 > 3$ – heavily loaded bearings.

3.12. Friction characteristic:

for $S_0<1$ $$\frac{\mu}{\psi} = \frac{3}{S_0} \tag{14}$$

for $S_0>1$ $$\frac{\mu}{\psi}=\frac{3}{\sqrt{S_0}} \quad (15)$$

3.13. Friction energy loses:

Great amount mechanical energy is converted to head because the influence of friction. Power used for friction resistance overcoming P_G in W is:

$$P_G = F\cdot\mu\cdot v \quad (16)$$

3.14. Compulsory cooling and heat distribution of bearing:

$$Q_P = \rho\cdot c\cdot q\cdot\left(\vartheta_i-\vartheta_u\right) \quad (17)$$

By rule, it is taken (υ_i - υ_u) = 20 K.

Oil flow in area of hydodynamical pressure is determined by:

$$q = D^3\cdot\psi\cdot\omega\cdot K_{ql} \quad (18)$$

3.15. Thermal stability of bearing:

Stationary working temperature of bearing is 50÷60 °C, rarely 70÷80 °C, and especially over 100 °C. With circular lubrication, border working temperature is υ_{Llim} = 100 °C.

For stationary condition is necessary that energy loses are equal to distributed:

$$P_G = Q_P \quad (19)$$

3.16. Hydodynamical floating condition.

$$n_{gr}=\frac{F\cdot 10^{-7}}{\eta\cdot C_{gr}\cdot V_L} \quad (20)$$

4. PROGRAM MODULE FOR CALCULATIONS OF RADIAL JOURNAL BEARINGS

Figure 4 gives user interface for data input necessary for carrying ability calculations for hydrodynamical journal bearings. First two data to input are diameter (D) and width (B) of bearing. After that, program calculates characteristic φ. Then intensity of force (F) and round velocity (n) have to be entered. After that, user has to choose lubricant oil.

Gradation viscosity for different oil types is given in Figure 5. User gives one of four gradation modules, program compares then and adopts standard ISO VG mark for further calculations.

Next group of input data is connected for thermal stability and it is necessary to input working temperature of the bearing and output oil temperature. Program possesses limitation module and it is not possible to input non adequate data. Final input concerns about material of tilting pad. It is done at special mask, shown in Figure 6.

Program offers list of standard allows, referenced in literature, but, gives possibility to create user database of materials, which are not given by standard.

Finally, there is testing module for specific load and after this user gets clear message if material is satisfactory or not.

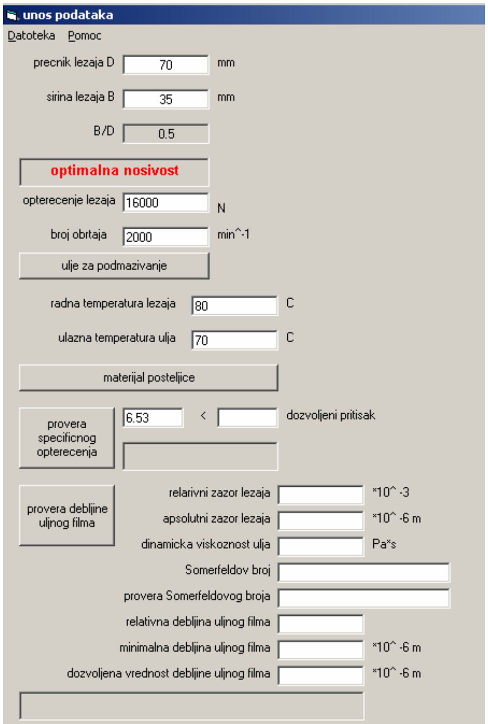

Fig. 4. User interface for data input

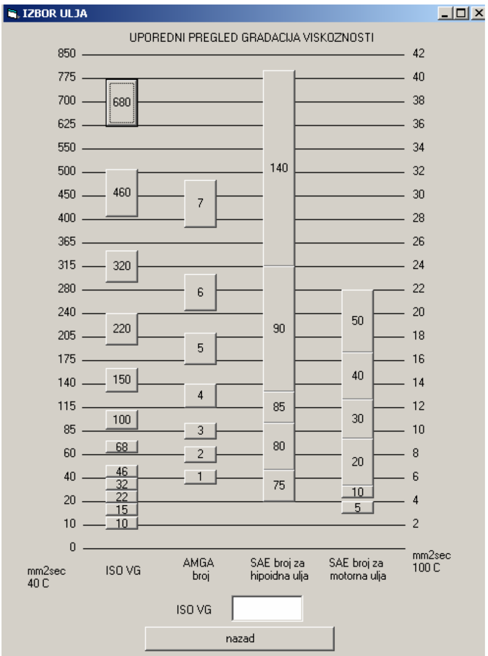

Fig. 5. Oil selection

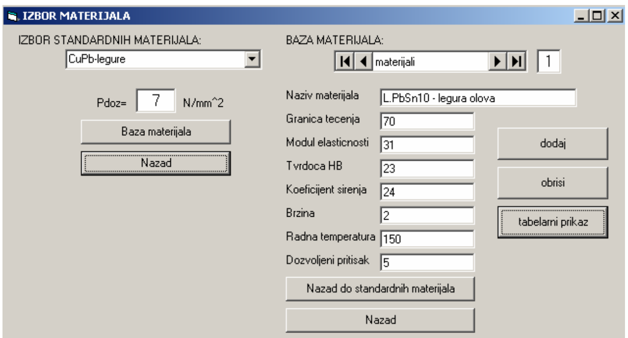

Fig. 6. Material mask

Further calculations consider carrying ability of bearing and thickness of the oil film. Absolute and relative gap, dynamical viscosity, Somerfield's number, relative and minimal thickness of oil film, also. As output from calculations, software gives information wills the hydrodynamical floating will be adequate or not. Diagrams of temperature (ϑ) and dynamical viscosity (η), and kinematical viscosity (v) (Figure 6.), diagram of Somerfield's number (S_o) and relative thickness of oil film (δ), relative eccentricity (ε) for various ratios *B/D* (Figure. 8.) are used for calculations.

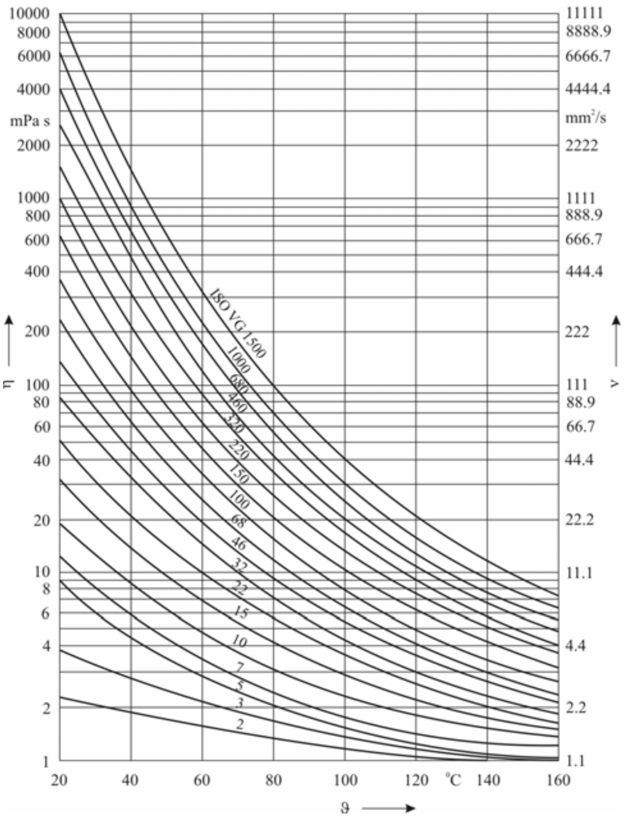

Fig. 7. Diagram temperature (ϑ) -dynamical (η) kinematical (v) viscosity of oil

Curves have been separated to 2 or more parts and with Lagrange polynomial interpolation (21) we came to the interpolation functions used in program (Example 2.).

$$P_n(x) = \sum_{k=0}^{n} y_k L_k(x)$$
$$L_k(x) = \frac{(x-x_0)...(x-x_{k-1})(x-x_{k+1})...(x-x_n)}{(x_k-x_0)...(x_k-x_{k-1})(x_k-x_{k+1})...(x_k-x_n)} \quad (21)$$

Example 1.-dependency temperature (ϑ) and viscosity

```
If isovg = 220 Then
    If jota < 90 Then
    eta = -2.01048 * 10 ^ -11 * (-167.18 + q) * (22943.1 + (-299.713 + q) * q) * (12597.2 + (-216 + q) * q) * (4056.62 + (-110.584 + q) * q)
    End If
    If jota >= 90 Then
    eta = 3.90625 * 10 ^ -7 * (41471.7 + (-404.401 + q) * q) * (17376.7 + (-243.599 + q) * q)
    End If
End If
```

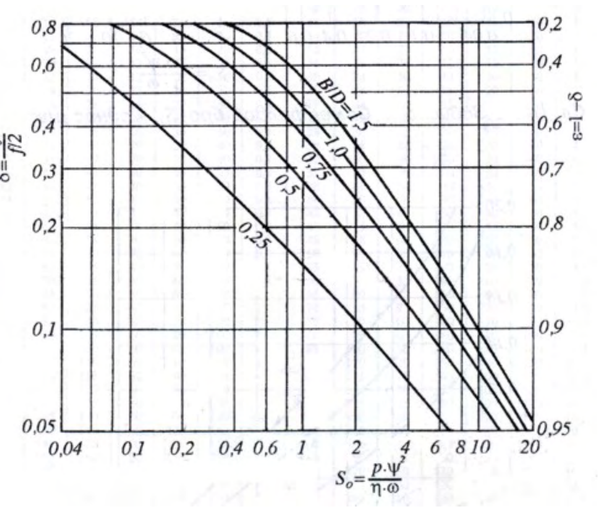

Fig. 8. Somerfield's number S_0 and relative oil film thickness (δ) dependency

Value of relative oil film thickness δ, is determined from dependency of Somerfield's number S_0 and ratio *B/D*. Since this value is defined only for certain values of B/*D* (Figure 8), for any other value between two existing, program recalculates then according to the Lagrange polynoms and uses linear interpolation (of those two values) concerning Somerfield's number and finds precisely relative thickness of oil film (Example 2.).

Example 2.- Somerfield's number and relative oil film thickness dependency

```
If bd > 1 And bd < 1.5 Then
      If x >= 0.22 And x < 1 Then
d10 = 0.44 + (-0.461538 + (0.293522 - 0.24179 * (-0.6 + x)) * (-0.22 + x)) * (-1 + x)
      End If
      If x >= 1 And x < 6 Then
d10 = 0.12 + (-0.064 + (0.0146667 - 0.00341667 *(-4 + x)) * (-1 + x)) * (-6 + x)
      End If
      If x >= 6 And x <= 19 Then
d10 = 0.05 + (-0.00538462 + 0.00041958 * (-6 + x)) * (-19 + x )
      End If
      If xd >= 0.35 And xd < 1 Then
d15 = 0.54 + (-0.4 + (0.3 - 0.166667 * (-0.6 + x)) * (-0.35 + x)) * (-1 + x)
      End If
      If x >= 1 And x < 6 Then
d15 = 0.15 + (-0.078 + (0.0176667 - 0.00516667 * (-4 + x)) * (-1 + x)) * (-6 + x)
      End If
      If x >= 6 And x <= 20 Then
d15 = 0.0505 + (-0.00710714 + 0.000539286 * (-6 + x)) * (-20 + x)
      End If

m = ((d15 - d10) * (bd - 1)) / 0.25
delta = d10 + m
End If
```

User interface (Figure 9.) is for thermal stability testing of bearing and gives great amount of control values like flow coefficient, friction coefficient, energy loses form friction influence, oil flow and working temperature are.

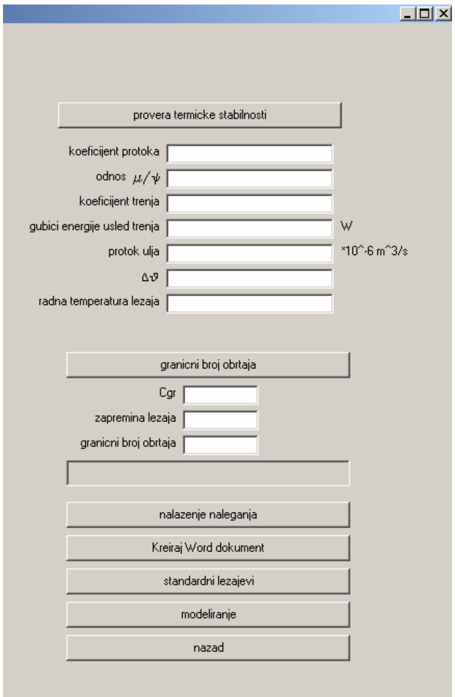

Fig. 9. User interface for thermal stability testing

Next program module calculates energy loses because of the friction (P_G) and compares it to the values Q_p. There we have difference form output temperature (ϑ_i) and input temperature (ϑ_u) of oil. When we add half of the output temperature to the input temperature, we get working temperature of oil.

For radial journal hydro dynamical bearings, it is very important to check maximal round speed value. After this check, program calculates border rotating frequency of the bearing.

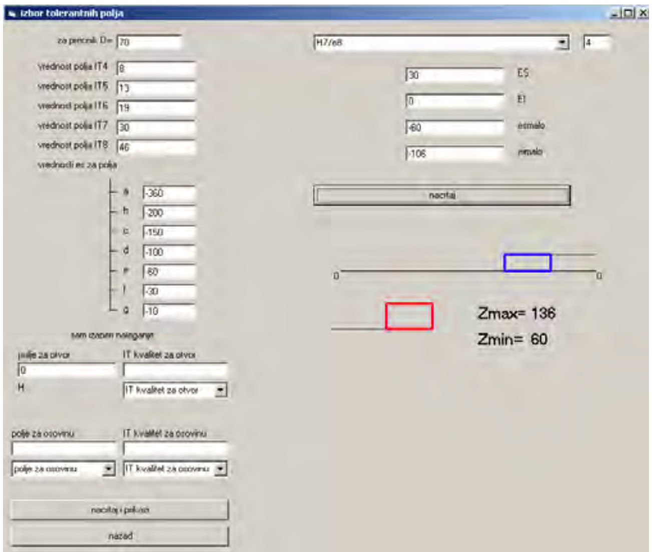

Fig. 10. Fitting

Very important part of calculations concerns about dimensions fitting. Inadequate choice of fitting could give smaller GAP then necessary for hydrodynamical floating. Minimal value of oil film thickness has to be always present in bearing.

Figure 10. shows choice of fitting and standard tolerance fields. Right side of the interface window gives numerous examples of already used and standard values. All the values are standard and given in literature as examples that become rule. Usage of those fitting will provide absolute GAP of bearing and while lower left corner of the interface gives possibility to choose manually tolerance field, ISO quality of the field for shaft and tilting pad. After selection, software calculates all necessary values: tolerance fields, values of tolerances, dimensions and graphical display of all values. User only has to choose selected tolerance field and confirm his decision.

After confirmation, software returns to the previous module and calculates values necessary for existence of minimal oil film thickness. There are two critical options – if assembly is manufactured with minimal or maximal GAP (Figure. 11.).

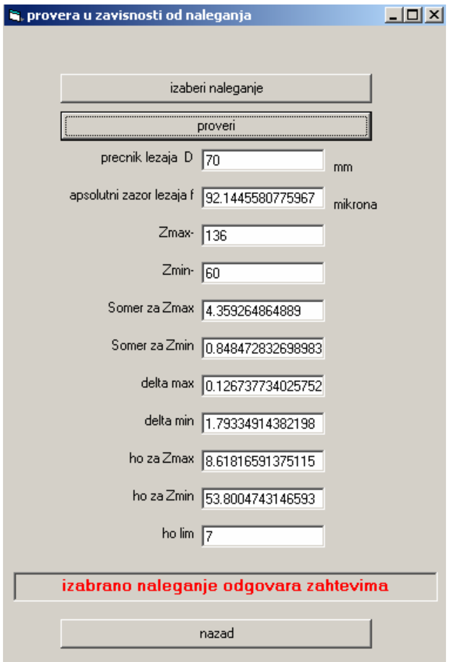

Fig. 11. Carrying ability in function of chosen fitting

It is explicitly shown if the selected fitting is adequate or not. After confirmation of this information, program returns to the main frame. User can forward his calculation, input and output data to the Microsoft Word.

5. PROGRAM MODULE FOR RADIAL JOURNAL BEARINGS MODELING

This module offers to the user 8 standard journal bearing types (Figure 12).

After selection of a single type, software offers selection (tilting pad or complete journal bearing) and allows shaft diameter selection based on which will copy all necessary data from standard database. All the data given in the interface is according to the ISO standard. Some of the data are parametric – enable creation family of similar parts, but, most of the data are not, because the demands of ISO (Figure 13.). Interface shows all the data to the user and gives him possibility to change some of the data.

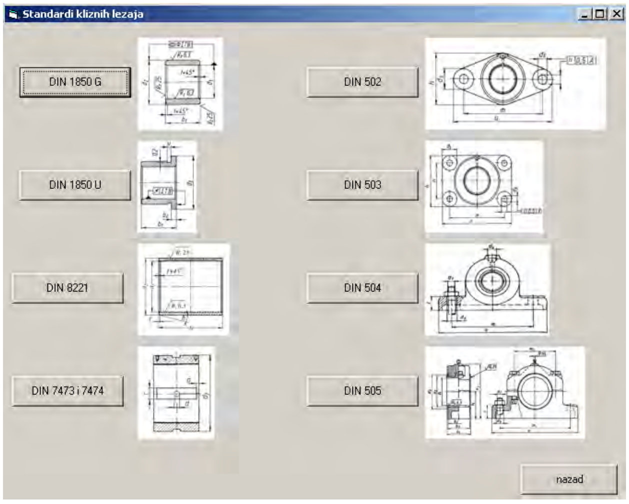

Fig. 12. User interface with 8 standard journal bearings and tilting pad

So, here are several variant solutions of a single bearing and they can be generated also. All bearings can be generated in the CAD application Autodesk Inventor.

Parameters

Model Parameters

Parameter Name	Unit	Equation	Nominal Value	Tol.	Model Value		Comment
d0	mm	d1stand	40.000000		40.000000		
d1	mm	d3stand	90.000000		90.000000		
d2	mm	b1stand - 4 mm	66.000000		66.000000		
d3	deg	0 deg	0.000000		0.000000		
d4	mm	d1stand * 1.5 ul	60.000000		60.000000		
d5	mm	2 mm	2.000000		2.000000		
d6	deg	0 deg	0.000000		0.000000		
d7	mm	2 mm	2.000000		2.000000		
d8	mm	1 mm	1.000000		1.000000		
d10	mm	d1stand * 1.5 ul	60.000000		60.000000		
d11	mm	2 mm	2.000000		2.000000		
d12	deg	0 deg	0.000000		0.000000		
d13	mm	2 mm	2.000000		2.000000		
d14	mm	1 mm	1.000000		1.000000		
d16	mm	1 mm	1.000000		1.000000		
d17	mm	h1stand	60.000000		60.000000		
d18	mm	astand	190.000000		190.000000		

Fig. 13. Table from AI – parameters of a single 3D shape (shaft and tilting pad) defined in AI

Dynamical connection between software for calculations and CAD – AI is made by Microsoft Excel Worksheet (Figure 14). Example 3 gives software code for Microsoft Excel Worksheet generation.

Example 3.

```
Dim x As Object
 Set x = CreateObject("Excel.Sheet")
 x.Application.Visible = True
 x.Application.Workbooks.Add
x.Application.Workbooks.Open      App.Path      &
"\EI\din_8221.xls", , True
x.Application.Visible = True
x.Application.Cells(1, 1).Value = "d1stand"
x.Application.Cells(2, 1).Value = "bstand"
x.Application.Cells(3, 1).Value = "d2stand"
x.Application.Cells(4, 1).Value = "fstand"
x.Application.Cells(1,2).Value = Val(Text1.Text)
x.Application.Cells(2,2).Value = Val(Text2.Text)
x.Application.Cells(3,2).Value = Val(Text3.Text)
x.Application.Cells(4,2).Value = Val(Text4.Text)
```

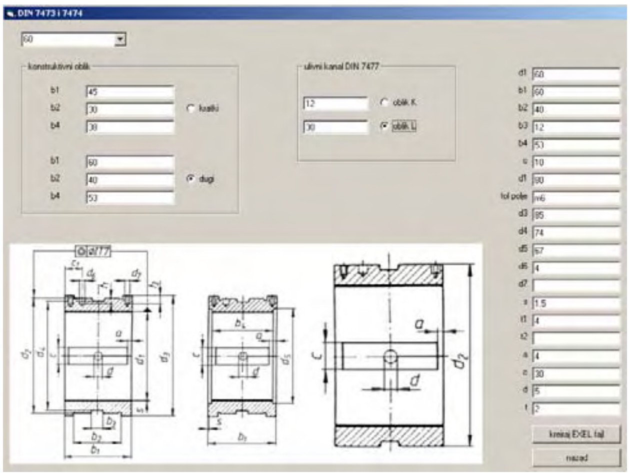

Fig. 14. User interface which forms Microsoft Excel Worksheet – dynamical connection to the CAD - AI

Outputs from this program module are 3D models of tilting pad and complete journal bearing. These models can be modified, assembled or used for technical documentation generation (Figure 15, 16, 17 and 18).

Fig. 15. 3D model of tilting pad generated by AI

Fig. 16. 3D model of journal bearing generated by AI

Fig. 17. 3D model of tilting pad generated by AI

Fig. 18. 3D model of journal bearing generated by AI

6. CONCLUSIONS

Based on the given, conclusions might be:

1. Faculty of Mechanical Engineering in Nis is developing an integrated system for design of power transmitters – PTD.
2. Integral part of this system is program module for automated calculation and design of radial journal hydrodynamical bearings.
3. Developed intelligent program module for calculations and model generation in Cad gives automated approach of design process. Automatism of iterative process, necessary for journal bearing calculations, gives much faster and more precise solutions then normal – made by hand calculations.
4. There is a dynamical connection between calculations software and CAD system Autodesk Inventor. Connection is achieved with Microsoft Excel Worksheet.

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CORRESPONDENCE

Dragan MILČIĆ, Prof. D.Sc. Eng.
University of Niš
Mechanical Faculty of Niš
Aleksandra Medvedeva 14
18000 Niš, Serbia
milcic@masfak.ni.ac.yu

Vojkan MILOŠEVIĆ, M.Sc. Eng.
University of Niš
Mechanical Faculty of Niš
Aleksandra Medvedeva 14
18000 Niš, Serbia
vojamilosevic@masfak.ni.ac.yu

Miroslav MIJAJLOVIĆ, M.Sc. Eng.
University of Niš
Mechanical Faculty of Niš
Aleksandra Medvedeva 14
18000 Niš, Serbia
miroslav_mijajlovic@masfak.ni.ac.yu

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There were 21 papers on KOD 2000, 36 papers on KOD 2002, 43 papers on KOD 2004 and 79 papers on KOD 2006.

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