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STUDIES AND RESEARCH CONCERNING OF THE CONSTRUCTIV AND FUNCTIONAL OPTIMISATION OF THE ENGINE AXES IN ROTATION MOTION FROM THE MECHANICAL STRUCTURE OF THE MACHINES AND MECHANISMS

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Abstract: *The application of the calculus program described in this paper had confirmed and enlightens series of useful aspects for the design activity of the driving axes generating rotation movement. The calculus relations presented in the paper take into consideration also the influence of frictions on the necessary power at the drive element of the rotation couple.*
Key words: *driving axe, friction, driving force, optimization function.*

1. INTRODUCTION

The engine (drive) axes which are taken into account in this paper are used in device building with mechanical driving, machine tools or in cinematically chains structure of the industrial robot. In fact there are the rotation couplings of five classes with one mobility degree. In generally these are studies like an ideal couple without friction or take accounts only a part of the friction from the couple. The main aim of this kind of axe is to realize a useful mechanical work by moving a known force under a pressure named driving force.

As you can see in figure 1 indifferently of building shape the axe is made of by a fixed element on which is laid the fixed part of the driving engine and a mobile element, on his extremity acts the external load (useful load).

A Cartesian system is attached to the fixed element, the "z" axe is lengthways of relative speed "ω". The same direction has also the load respectively the motor torque from axe. In the general case the external force (the compression forces or torque, the technological forces or torque, the cutting forces or torque or manipulate forces) is known by force value "$\vec{F}$" and torque value "$\vec{N}$". These are position of the coordinate system origin by force's arm noted with "$\vec{b}$" (perpendicular line from reference system origin on the support line of the force vector). Also it is considered that the driving force or torque act " centric" in origin "O" of the coordinate system which was chosen.

The making constructive solutions of the driving axes of the rotation met in mechanical structure shown are different from case to case.

A special problem at the design of this kind of axe is the choice and the dimension of the driving system, so to ensure the imposed conditions. This kind of calculus can be made correctly if you take account all the parameters which influence the driving force or torque and take part at the good working of the axe.

The main functional and constructive parameters of this kind of axe are:

-Loaded the couple throughout the force value and reactive torque $\left[\vec{F} si \vec{N}\right)\right]$

-The friction coefficients depends of the lubricate and cooling, materials proprieties, surfaces roughness, frictions type, oil type, geometrical precision and mechanical parameters (speeds and accelerations)

-Forces' arm and it position through (b_x, b_y, b_z,)

-The nominal constructive dimensions

-Working temperature

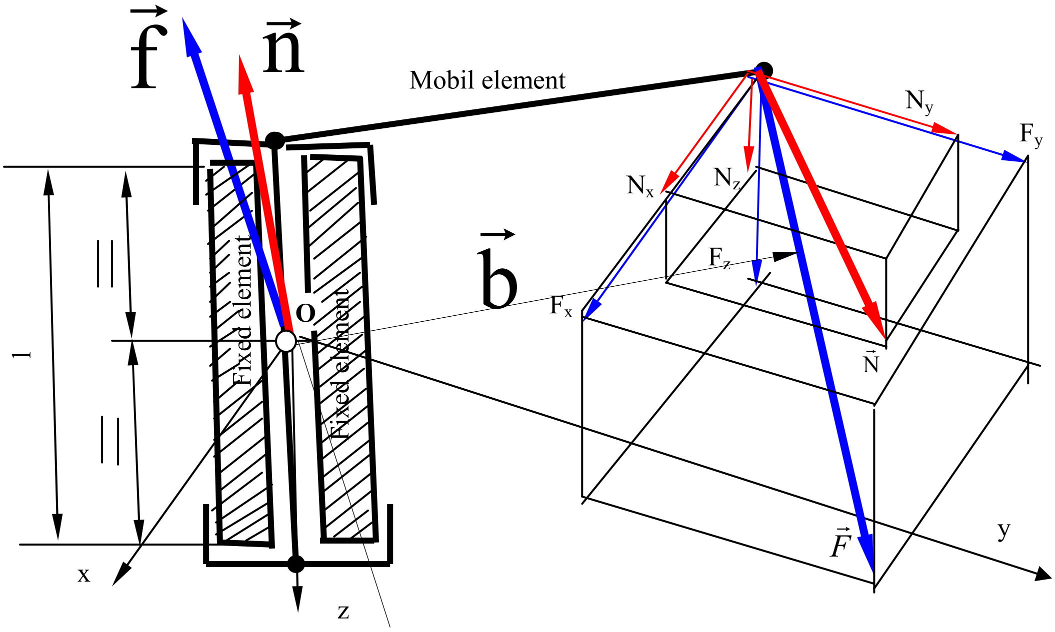

Fig 1. Cinematically scheme of the rotation ax**e**

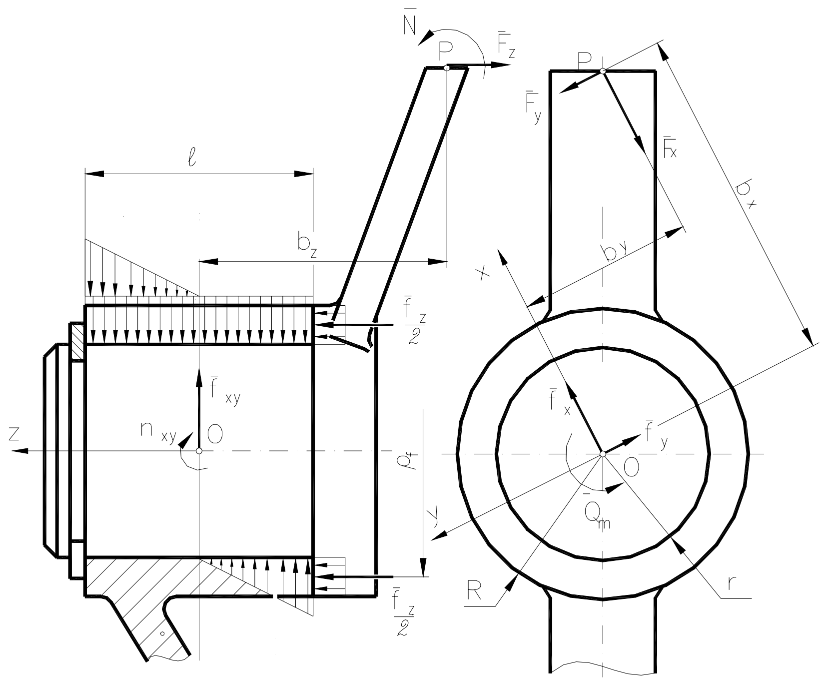

Fig.2. The shape and constructive dimensions of the rotation axe

2. THE CALCULUS RELATIONS OF THE TORQUE OR DRIVING FORCE

As we can see in [1] and [2] the engine and driving system is dimensioning after the driving force or torque value determinate in point "O".

The driving torque in the rotation axe with sliding friction is determinate with relations like

$$Q_{mf} = Q_m + Q_f = ne_z \tag{1}$$

$Q_m = n_z$ -The driving torque in driving axes without friction (ideal):

$Q_f = n_f$ - The driving torque friction:

For some concrete situations we have:

-The couple without radial clearance and uniform radial pressure.

$$ne_z = n_z + \\ + \operatorname{sgn}\left(\vec{v}\right)\left[\mu r f_{xy} + \mu_z \rho_f \left|f_z\right| + 3\mu \frac{r}{l} n_{xy}\right] \tag{2}$$

- The couple without radial clearance and variable radial pressure.

$$ne_z = n_z + \\ + sgn\left(\vec{v}\right)\begin{bmatrix} 1{,}27\mu r f_{xy} + \mu_z \rho_f \left|f_z\right| + \\ + 3{,}81\mu \frac{r}{l} n_{xy} \end{bmatrix} \tag{3}$$

Where:

$$\rho_f = \frac{2}{3}\frac{R^3 - r^3}{R^2 - r^2} \tag{4}$$

$$n_z = b_y F_x - b_x F_y - N_z \tag{5}$$

$$n_y = -b_z F_x + b_x F_z - N_y \tag{6}$$

$$n_x = b_z F_y - b_y F_z - N_x \tag{7}$$

$$f_x = -F_x \tag{8}$$

$$f_y = -F_y \tag{9}$$

$$f_z = -F_z \tag{10}$$

$$n_{xy} = \sqrt{n_x^2 + n_y^2} \tag{11}$$

$$f_{xy} = \sqrt{f_x^2 + f_y^2} \tag{12}$$

- r, R and l - the nominal constructive dimensions

-μ The friction coefficient which corresponds with the cylindrical surface of the journal,

-μ_z the friction coefficient, which corresponds with the frontal plane surface, named the "pining friction coefficient”

-ν=ω-relative speed from the coupling.

3. THE DIMENSIONING RELATIONS AND MECHANICAL STRESSES

From the figure result a number of three dimensions on which value must be established; these are:

-r,(d) –nominal radius (diameter) of the journal

-R,(D) -radius (diameter) of the flange

-l -length (or breadth) of the couple

Knowing the torso components calculated in point "O", respectively the resulted vector force $\overline{f} = \left[f_x\ f_y\ f_z\right]^T$ and the resulted torque $\overline{n} = \left[n_x\ n_y\ n_z\right]^T$ these create the contact pressure on the semi cylindrical surface by "r" radius and "l" length and on the ring circular surface characterized by "r" and "R" radius. The maximum value of this pressure is calculated applying the overlapping effects basic.

On the semicylindrical surface characterized by dimensions "r" and "l", the contact pressure can be calculated with relations:

$$p_{rMAX} = \frac{f_{xy}}{2rl} + \frac{f_{n_{xy}}}{2rl} = \frac{f_{xy}}{2rl} + \frac{3n_{xy}}{rl^2} \tag{13}$$

On the ring circular surface characterized by radius "r" and "R", the value of the contact pressure determinate by f_z can be written:

$$p_{f_z} = \frac{f_z}{\pi\left(R^2 - r^2\right)} \tag{14}$$

Inequations:

$$p_{r\,MAX} \le p_a \text{ and } p_{f_z} \le p_a .$$

Can be used at the contact pressure checking.

4. ESTABLISH THE OPTIMIZATION FUNCTIONS

The relations 2, 3,13 and 14, presented in the upper part can be used when is done a dimensioning or checking calculus or a driving engine or a constructive dimensions of the axe.

The application from one side of these relations is not recommended because it never leads to an optimal solution.

Optimization programs have to include as many relations as possible, for this establishing an optimization function. The optimization function must contain explicit or implicit all parameters which define the axe. The values or the variation field of these parameters must be establishing on design data named entrance data.

The opposition function, which will be the base of the calculus program, is established starting with relations who define the torque or driving force, where is done the following replacements:

- The constructive dimensions are the one to satisfies at the limit the main mechanical stress (dangerous);
- dimension “l” is replaced with the substitution;
- l =2α r-where: ”α” is named the dimensional coefficient chooses from specialty literature

In this conditions the optimization main function for the rotation axe has the expression (2,3) together with equations:

- The couple with uniform radial pressure.

$$4p_a r^3 - \frac{f_{xy}}{\alpha} r - \frac{3}{\alpha^2} n_{xy} = 0 \qquad (15)$$

- The couple with variable radial pressure.

$$\pi P_a r^3 - \frac{f}{\alpha} r - \frac{3}{\alpha^2} n = 0 \qquad (16)$$

- For the frontal surface of the couple.

$$R = \sqrt{\frac{f_z}{\pi p_a} + r^2} \qquad (17)$$

The real and positive solutions of the upper part equations represent the constructive dimensions which satisfies at the limit the imposed strength conditions. These solutions are take account in the opposition and calculus program.

5. THE PROGRAM OF CALCULUS AND OPTIMIZATION

Based on optimization functions is established the program of calculus and optimization. The program takes account like in the optimization function, the expression of the driving force or torque. For the case when is taken account the friction from the axe the program is written in a base variant for the rotation axe and one for translation axe. The constructive dimensions are established using the value of the admissible stress for the dangerous stress (usually the contact pressure). In this manner is done also a dimensioning of the axe at the considerate stresses.

The program is written in ANSI C, he found the extreme value (minim or maxim) of the function with more variables. The possible field for independent variable is run from the minimum value to maximum value, with a constant pitch. For finding the minimum of the function suppose that corresponding to the minimum values of the optimization function variables. Than it is run the entire field, and than in case that the program fined a value smaller than the supposing value, the minim will be replace with this value.

This algorithm guarantees the finding the minimum or maximum only after the running all possible values from the parameters values interval.

The program contents four functions:

-main(): represent the starting point and have 14 cycle for overlapping, only one for each independent variable; she is responsible for the running of the value space in which you look for the extreme value of the function.

-solve(): in the optimization function occur the problem of the determination of the polynomial equations solutions, the method used in this case is Bairstow method; this method decomposed the polynom degree "n" into a product of polynomial degree 2 eventual 1, the value and the number of solutions is stocked in “nrsol” and in “sol” with precision “prec”;

-q(): contain the code for the function of which minim and maxim will be find, these are calculated in variable Q,V and QV; the last one is an optimization function defined through square sum of Q and V for finding a lot of parameters where both functions aspire simultaneous to an extreme value.

-init(): make the ignitions of the cycles "for" so if it is necessary some of them are passed over in case if you need to keep the parameter subset constantly on which depend the functions whom extremes are looking.

The parameters, which are included in the program, are the couple's parameters which value is established with the methods presented.
The basic method of the program consists of:
-The calculus of the maximum value of the driving force or torque.
-The calculus of the minimum value of the driving force or torque.
-The calculus of the minimum value of the material included, respectively:

$$\vee = \frac{\pi d^2}{4} l; \qquad (18)$$

-The calculus of the minimum auxiliary optimization function as in the relation:

$$v^2 + ne^2 = \min \qquad (19)$$

6. CONCLUSIONS AND RESULTS

Applying this calculus and optimization program for designing this kind of axes we obtain the following advantages:
-correct choosing of the engines and driving systems
-avoiding the limit situations when occur the blocking phenomena's or excessive wears of active surfaces
-correct using of the materials which form the axe
-adoption of the advantages solutions regarding the forces system and external torque
-adoption of the solutions regarding the manufacturing and technology concurring with the other parameters
This program has simplified alternative, which have the following advantages:
-reducing the calculus time;
-could be used some large field parameters with smaller value of the pitch;
-it requires cheaper IT
So, if in the entrances data we have included the dimension value of the couple than we can give up to the "solve" function from basic program and if we want to dimension the driving engine for a special case we will follow only the maximum value calculus of the basic function.

Partial results of the above mentioned calculus programs are presented in Annex 1

q > minim
miu=0.1
miuz=0.12
Nx=-9.9e+005
Ny=-6.3e+005
Nz=-2.1e+005
Fx=-3.9e+002
Fy=-6e+002
Fz=2.9e+003
L=0
e=0
pa=0.8
fi=0
alfa=0.8 -> qmin=479971.96127679 : r=120.56053267747

v > minim
miu=0.1
miuz=0.12
Nx=-9.9e+005
Ny=-6.3e+005
Nz=-2.1e+005
Fx=-3.9e+002
Fy=-6e+002
Fz=2.9e+003
L=0
e=0
pa=0.8
fi=0
alfa=0.8 -> v minim=8808162.7356066 : r=120.56053267747

qv > minim
miu=0.1
miuz=0.12
Nx=-9.9e+005
Ny=-6.3e+005
Nz=-2.1e+005
Fx=-3.9e+002
Fy=-6e+002
Fz=2.9e+003
L=0
e=0
pa=0.8
fi=0
alfa=0.8 -> qv minim=77814103860540.7 : r=120.56053267747

q > minim
miu=0.1
miuz=0.12
Nx=-9.9e+005
Ny=-6.3e+005
Nz=-2.1e+005
Fx=-3.9e+002
Fy=-6e+002
Fz=2.9e+003
L=0
e=0
pa=0.8
fi=0
alfa=1.1 -> qmin=410590.721246949 : r=97.5702328357907

v > minim
miu=0.1
miuz=0.12
Nx=-9.9e+005
Ny=-6.3e+005
Nz=-2.1e+005
Fx=-3.9e+002
Fy=-6e+002
Fz=2.9e+003
L=0
e=0
pa=0.8
fi=0
alfa=1.1 -> v minim=6419845.51699366 : r=97.5702328357907

qv > minim
miu=0.1
miuz=0.12
Nx=-9.9e+005
Ny=-6.3e+005
Nz=-2.1e+005
Fx=-3.9e+002
Fy=-6e+002
Fz=2.9e+003
L=0
e=0
pa=0.8
fi=0
alfa=1.1 -> qv minim=41383001202437.7 : r=97.5702328357907

q > minim
miu=0.1
miuz=0.12
Nx=-9.9e+005
Ny=-6.3e+005
Nz=-2.1e+005
Fx=-3.9e+002
Fy=-6e+002
Fz=2.9e+003
L=0
e=0
pa=0.8
fi=0
alfa=1.4 -> qmin=370460.679936953 : r=83.1293848953194

7. REFERENCES

[1] Turcu, I., *Cercetări privind influența frecărilor în construcția şi funcționarea roboților industriali*, Teză de doctorat, Universitatea Tehnica Cluj-Napoca, 2002.

[2] Turcu, I.,Belcin ,O.,Bojan S.,.: *Frecarea In cuplele de rotație şi translație la roboți,* Cluj-Napoca, Editura RISOPRINT,., ISBN 973-656-406-1, 2003

[3] Buzdugan, Gh., *Rezistența materialelor*. Bucureşti, EdituraTehnică, 1980

STUDII SI CERCETĂRI PRIVIND OPTIMIZAREA CONSTRUCTIVĂ ŞI FUNCȚIONALĂ A AXELOR MOTOARE CU MIŞCARE DE ROTAȚIE DIN STRUCTURA MECANICĂ A MECANISMELOR ŞI A MAŞINILOR

Rezumat: Aplicarea programelor de calcul descrise în această lucrare pune în evidență o serie de aspecte utile în activitatea de proiectare a axelor motoare care generează miscări de rotație. Relațiile de calcul prezentate în lucrare iau în considerare şi influența forțelor de frecare asupra puterii necesare la elementul motor al cuplei.

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