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TORQUE TRANSMITTED IN THE DISENGAGING PROCESS BY SAFETY CLUTCHES WITH BALLS AND SPHERICAL RABBETS

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Abstract—Safety clutches with balls may have various forms of the active rabbets, trapezoidal shape, tapered, cylindrical or spherical, these could be radial or frontal disposed, depending on the available gauge. The disadvantage of classical solutions consists in the fact that in the complete engaged working situation, the contact is punctiform or sometimes linear, but in the disengaging process, the contact is always punctiform. This paper aims to analyze the loads on the active elements of a safety clutch with spherical active rabbets, radial disposed, during the disengaging process when the ball is in contact with the active rabbet following a circular arc.

Keywords—safety clutch, spherical rabbets radial disposed, disengaging process, transmitted torque

I. Introduction

THE increase of capacity and productivity of a machine requires this to be more rapid, more rigid and to be performed with high precision to withstand to dynamic loads necessary in the production process [1], [2], [6]. In addition, the machine should be designed to incorporate into its construction as much automation. In this case, the production process stopping and the machine servicing become very costly [3], [4]. As a result, many companies provide their equipments against damage at overloads, as a result of some anomalies in operating or of some incorrect maneuvers of human operator, by incorporating into the kinematic chain of a reliable safety clutch [2], [5].

Regardless the type of overloads, dynamic – with very short action, or quasi-static – with long time action, they can lead to the machine damage and to its removal from operating. Consideration of all overloads, which can load the transmission, would lead to its excessive sizing; this situation can not be accepted in the current state of technique development. The mounting of a safety clutch into the kinematic chain of mechanical transmission can make maximum use of the mechanical properties of the materials used to manufacture the components of the transmission, reducing much the transmission gauge [10]. Among the constructive solutions of existent safety clutches, in many cases the clutches with balls or rollers are used. This paper proposes to analysis the safety clutch with balls radial disposed, with spherical rabbets.

Safety clutches with balls must provide the following functional performances [6], [10]: the disengaging precision, the sensitivity to disengaging, the transmission capacity of load, high durability. The increase of the disengaging precision is achieved by the elimination of clearances among the clutch elements ([2], [7], [8]). The increase of sensitivity to disengaging is obtained by the use of disc springs with regressive characteristic [7], [8]. The increase of the transmission capacity of load is achieved by the use of pressure disks and of the disc springs [7]-[9]. The durability increase is obtained through the use of constructive solutions that do not allow the adjustment of torque transmitted [7], namely by reducing the shocks in the engaging process (that is achieved by the shape of active rabbets, different at the coupling side compared to that at disengaging [5]); by the choice of the coupling profile so that to provide a linear or surface contact [6]; respectively by the interrupting the power supply or by the clutch blocking in disengaged position [7], case when the re-coupling is done manually.

II. The Description of Safety Clutch

The safety clutch with balls and spherical rabbets, radially disposed and pressure system with pressure disk [10] is presented for the complete engaged working situation in Fig. 1, and at the end of the disengaging process, when the ball comes out completely from the spherical rabbet, in Fig. 2. The balls 2 are disposed, both, into the spherical rabbets of the semi-clutch 3, and into the cylindrical holes of the semi-clutch 1. The semi-clutch 1 is assembled by means of flange screws 9. The pressure disk 4 is centered both on flange 9 and on the semi-clutch 1, through the cylindrical part of smaller diameter, both being made by sliding fits.

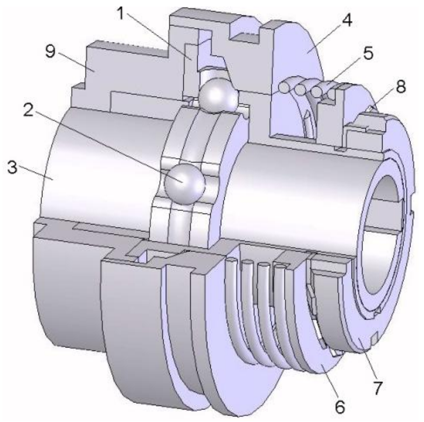

Fig. 1. Safety clutch in the complete engaged working situation.

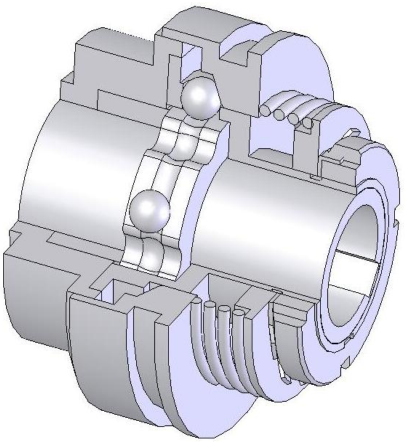

Fig. 2. Safety clutch at the end of the disengaging process.

The pressure disk 4 acts on the balls to keep them into the spherical rabbets of the semi-clutch 3. The pressure disk 4 has on the inside two parts sloped at different angles, the first part having both the length and the angle of inclination, smaller compared to the second part. This disk is provided externally with a channel into which is introduced a feeler of an electric switch, which gives the command to stop the electric motor at the occurrence of some overloads in transmission. The pressure force on the pressure disk 4 is adjusted using the grooved nut 7, through flange 6, secured against dismantling using washers 8.

At the occurrence of some overloads in the transmission, the ball 2 acts on the pressure disk 4, this moves axially, compressing the cylinder spring 5. In the first stage, the ball 2 moves on the first part of the pressure disk 4, in the second stage it rotates on the edge between the two sloped parts, and in the third stage, the ball 2 moves on the second sloped part, of the same disk. In this time the ball comes out of active rabbet and guided by the circular channel reaches at the end of the disengaging process, on the cylindrical part of the semi-clutch 3, as shown in Fig. 2.

III. Loads in the Disengaging Process

Establishment of the reactions among the elements of safety clutch with the balls and active spherical rabbets, radially disposed and pressure disk as well of the torque transmitted by the clutch during the disengaging process is achieved depending on the relative movements of the elements, the variation range of the angle of relative rotation between semi-clutches, as well as the additional deformation of the springs. Fig. 3 shows a partial frontal section through the model of the safety clutch with balls and spherical active rabbets, radially disposed and pressure disk, in the disengaging process; Fig. 4, Fig. 5 and Fig. 6 present the partial axial sections through the clutch model for the three stages of the disengaging process. Corresponding to these working situations, is also represented the assembly of forces acting on the clutch, established based on the following calculation assumptions [6], [10]: the friction coefficients values during the motion are smaller than those static used in the analysis of the complete engaged working situation [6], [11]; the spring force increases due to additional compression of spring, as a result of the relative displacement of the semi-clutch 3 [6]; there are taken into account the friction forces and centrifugal force act on the balls; the balls are loaded evenly.

Relationships for the calculation of the torque transmitted by the clutch in the disengaging process M_{td} and of the reactions among the active elements of the clutch are obtained by solving the equilibrium equations for the balls, for the pressure disk 4 and for the semi-clutch 3, as shown in Table 1. Between the balls and the semi-clutch 3 is considered the friction coefficient in motion μ, between the balls and the semi-clutch 1 is the friction coefficient in motion μ_1 and between the balls and the pressure disk 4 is the friction coefficient in motion μ_2. By solving the system of equations shown in Table 1, there can be obtained the expression of normal reaction R_n and the relation for determining the torque M_{td} transmitted by the clutch in the disengaging process, presented in Table 2. At the end of the disengaging process, the clutch transmits the remanent torque M_{tr} that can be determined taking into account the fact that the spring is no longer compressed in addition after the ball comes out completely from the active rabbet. Assuming that between the balls and semi-clutch the friction coefficient is the same as during the disengaging process, the determination relationship of the remanent torque becomes

$$\mathbf{M_{tr} = zF_{max}A_{2r}\left(A_{1r} - k\right)\cdot} \\ \mathbf{\cdot\left[S_{21max}\cos\psi_{max} + \mu\left(S_{21max}\sin\psi_{max} - d_b/2\right)\right]} \tag{1}$$

where: $F_{max}=c(\delta_1+\Delta S_{max})$ represents the maximum force of spring that corresponds to a ball, at the end of the disengaging process; $\Delta S_{max}=\Delta S_{41\ III\ max}$ – the maximum variation of the spring deformation at the end of the disengaging process; $S_{21\ max}$ – the maximum value of the position function of ball 2 from the semi-clutch 1; $\psi_{max}=\alpha_{max}-\varphi_{13}$.

To highlight the influence of structural and functional parameters of the clutch on the normal reaction and the on the torque transmitted by the clutch in the disengaging process, a computer program was developed; the main menu of the program is presented in Fig. 7.

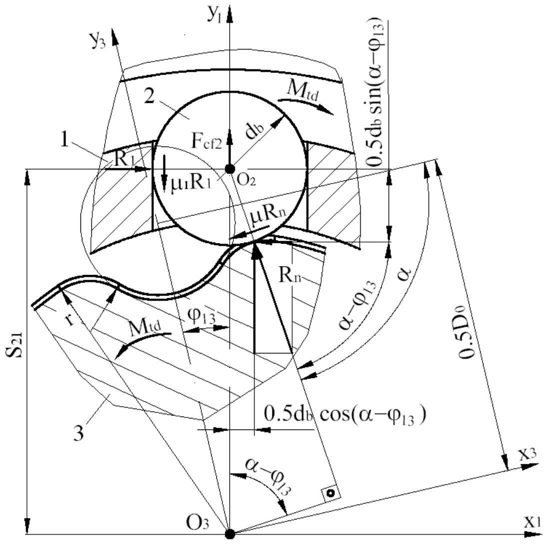

Fig. 3. Frontal section through the clutch and the forces among the active elements of the clutch.

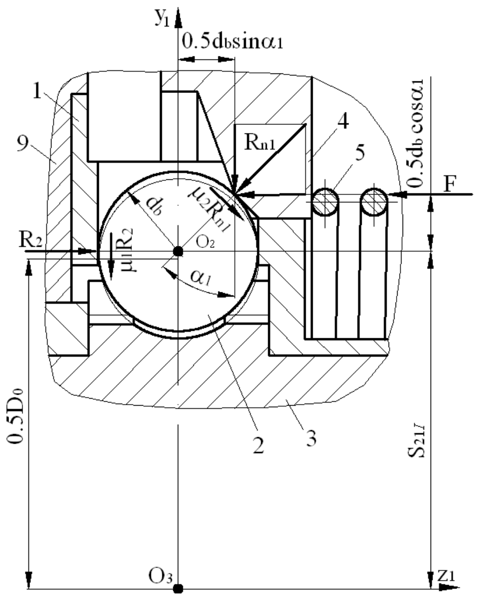

Fig. 4. Axial section through the clutch and the forces among the active elements of the clutch for the first disengaging stage.

The program was designed so that to allow the analysis of several clutches, namely of the safety clutch with balls radially disposed with spherical rabbets, with spherical rabbets and pressure disk, or with rabbets with balls, as shown in Fig. 8.

To emphasize the influence of structural and functional parameters of the clutch on the torque transmitted by the clutch in the disengaging process is considered one ball, the greater number of balls affecting only the value of torque transmitted and not its variation.

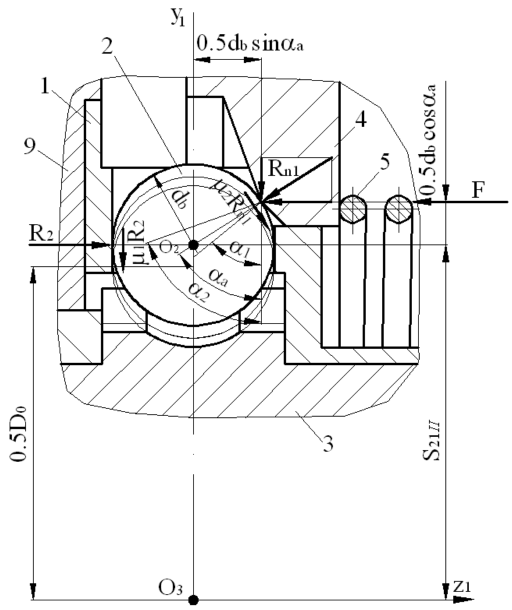

Fig. 5. Axial section through the clutch and the forces among the active elements of the clutch for the second disengaging stage.

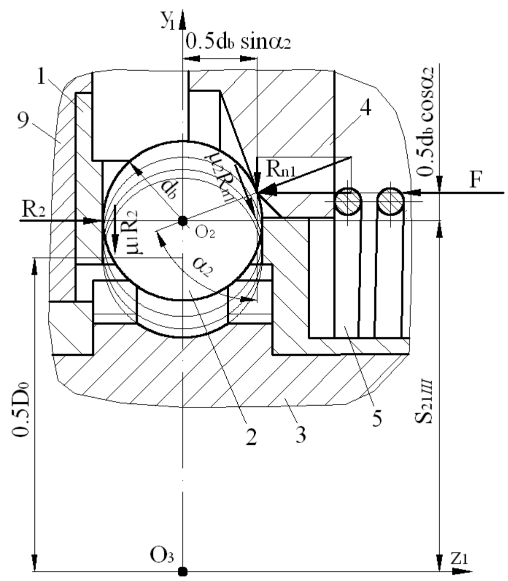

Fig. 6. Axial section through the clutch and the forces among the active elements of the clutch for the third disengaging stage.

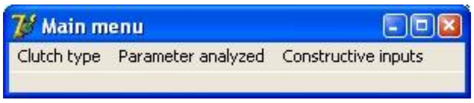

Fig. 7. The main menu of the program.

Fig. 8. Selection of the clutch type.

TABLE I
EQUILIBRIUM EQUATIONS

$\sum \overline{F_{x1}} = 0$: $R_1 - R_n(\cos\psi + \mu \sin\psi) = 0$; $\psi = \alpha - \varphi_{13}$, for the disengaging process from frontal plane;

$\alpha_{\max} = \frac{\gamma_3}{2} + \arccos\left[\cos\left(\alpha_0 - \frac{\gamma_3}{2}\right) - \frac{D_0}{d_b + 2r}\sin\frac{\gamma_3}{2}\right]$, the maximum angle of relative rotation of the ball 2 towards the semi-clutch 1

$\varphi_{13\max} = \frac{\gamma_3}{2} = \arctan\frac{(d_b + 2r)\cos\alpha_0}{D_0 - (d_b + 2r)\sin\alpha_0}$, the maximum angle of relative rotation in the disengaging process of the semi-clutch 1 towards the semi-clutch 3

$\gamma_3 = 2\,\mathrm{arctg}\frac{(d_b + 2r)\cos\alpha_0}{D_0 - (d_b + 2r)\sin\alpha_0}$,

$\alpha_0 = 30^\circ ... 60^\circ$,

$D_0 = (3...5)d$, $d_b = (8...20)$ mm, $r = (2...6)$ mm

$\sum \overline{F_{y1}} = 0$: $R_n(\sin\psi - \mu\cos\psi) - \mu_1 R_1 - R_{n1}(\cos\theta + \mu_2 \sin\theta) - \mu_1 R_2 + F_{cf\,2} = 0$

$\theta = \alpha_1$, $\theta = \alpha_a$ or $\theta = \alpha_2$ for the three stages of the disengaging process from axial plane

$\alpha_1 = 20^\circ ... 40^\circ$,

$\alpha_2 = 45^\circ ... 75^\circ$,

$\alpha_{a\max} = \arccos\frac{D_0 + d_b\cos\alpha_1 + 2a_1\sin\alpha_1 - 2S_{21II\max}}{d_b}$, the rotation angle of the ball around the intersection point of the two parts with different slopes of the pressure disk

$a_1 = (1...2)$ mm, the distance covered by ball on the first linear part of the pressure disk

$S_{21II\max} = \frac{1}{2}(D_0 + d_b\cos\alpha_1 + 2a_1\sin\alpha_1 - d_b\cos\alpha_2)$, position function of the ball 2, towards the semi-clutch 1 in case of the disengaging process from the frontal plane, corresponding to the second disengaging stage from the axial plane

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$\sum \overline{F_{z1}} = 0$: $R_2 - R_{n1}(\sin\theta - \mu_2\cos\theta) = 0$,

$\sum \overline{F_{z1}} = 0$: $R_{n1}\sin\theta - \mu_2 R_{n1}\cos\theta - F = 0$

$F = F_{arc}/z = c(\delta_1 + \Delta S)$ the force that corresponds to a ball in the disengaging process

F_{arc} – the spring force in the disengaging process,
z – number of balls,
c – the spring stiffness, (N/mm),
δ_1 – the initial deformation of spring, (mm) .

$\Delta S = \Delta S_{41I\max} = \frac{(D_0 + 2a_1\sin\alpha_1) - D_0}{2tg\alpha_1}$,

$\Delta S = \Delta S_{41II\max} = \frac{d_b}{2}(\sin\alpha_{a\max} - \sin\alpha_1) + a_1\cos\alpha_1$,

$\Delta S = \Delta S_{41III\max} = \frac{2S_{21\max} - D_0}{2\,\mathrm{tg}\,\alpha_2} + \left(\frac{d_b}{2tg\alpha_1} + a_1\right)\frac{\sin(\alpha_2 - \alpha_1)}{\sin\alpha_2} + \frac{d_b}{2}\left(\frac{1}{\sin\alpha_2} - \frac{1}{\sin\alpha_1}\right)$,

ΔS - the variation of the arc deformation for the three disengaging stages from the axial plane

$S_{21\max} = \frac{D_0 + (d_b + 2r)(\sin\alpha_{\max} - \sin\alpha_0)}{2\cos(\gamma_3/2)}$, the maximum value of the position function of the ball 2, towards the semi-clutch 1, in case of the disengaging process from the frontal plane, corresponding to the three disengaging stages from the axial plane

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$\sum \overline{M_{t3}} = 0$: $M_{td} - zR_n S_{21}\cos\psi - z\mu R_n\left(S_{21}\sin\psi - \frac{d_b}{2}\right) = 0$

$S_{21} = \frac{D_0 + (d_b + 2r)(\sin\alpha - \sin\alpha_0)}{2\cos\varphi_{13}}$, the position function of ball 2, towards the semi-clutch 1, in case of the disengaging process from the frontal plane.

TABLE II
RELATIONS FOR THE DETERMINATION OF THE REACTION FORCE R_n AND THE TORQUE M_{td}

$R_n = FA_2(A_1 - k)$

$k = 0.05...0.08$, proportionality coefficient of the centrifugal force in relation to the assembly spring force,

A_1, respectively A_2 – dimensionless values,

$A_1 = \frac{\cos(\theta - \varphi_1 - \varphi_2)}{\cos\varphi_1\sin(\theta - \varphi_2)}$, $A_2 = \frac{\cos\varphi\cos\varphi_1}{\sin(\psi - \varphi - \varphi_1)}$,

$\varphi = \mathrm{arctg}\mu$, $\varphi_1 = \mathrm{arctg}\mu_1$, $\varphi_2 = \mathrm{arctg}\mu_2$, the kinematic friction angles corresponding to the friction coefficients in motion μ, μ_1 respectively μ_2

$M_{td} = zFA_2(A_1 - k)[S_{21}\cos\psi + \mu(S_{21}\sin\psi - d_b/2)]$.

In all analyzed cases, there are considered as constants, the values of parameters that do not vary, respectively these have the following values: D_0=150 (mm), the diameter of balls arrangement; d_b=12 (mm), the diameter of balls; α_0=45°, the angle of the active rabbet profile; α_1= α_2=30° and 55°, the angles of the sloped parts of the pressure disk; r = 3 (mm), the rounding radius of the active rabbet profile to the groove on the inner surface of the semi-clutch 3; the assembly force of spring F_1=86 (N) (spring stiffness c=43 (N/mm) and the assembly deformation δ_1=2 (mm)); μ_0=0.06, μ_{01}=μ_{02}=0.08, the static friction coefficients and the friction coefficients in motion are reduced by 20%.

Plotting the diagram of variation of selected parameter is obtained in a specified range according to the relative rotation angle between the two semi-clutches, φ_{13}.

1) The torque variation M_{td}, depending on the diameter of balls arrangement is shown graphically in Fig. 9. The transmitted torque by the clutch during the disengaging process, M_{td}, increases with the increase of the diameter of balls arrangement, the maximum value, M_{tdmax} being obtained at the end of the first stage of disengaging process (φ_{13}=φ_{13Imax}). The difference between the value of torque at the beginning of the disengaging process and the maximum value, therefore the sensitivity to disengaging is higher for smaller values of the diameter of balls arrangement. For higher values of the diameter, a rapid decrease of the value of torque transmitted is recorded.

2) The torque variation M_{td}, depending on the diameter of balls is graphically represented in Fig. 10. The maximum transmitted torque by the clutch in the disengaging process, M_{tdmax}, still appears at the end of the first disengaging stage from the axial plane, but this value is much closer to the torque transmitted by the clutch at the start of the disengaging process, for reduced values of the diameter of ball, so the sensitivity to disengaging increases to small diameters of balls.

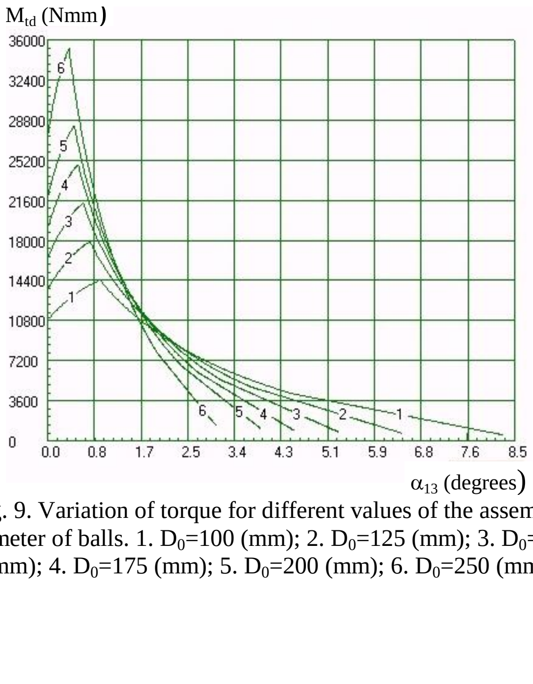

Fig. 9. Variation of torque for different values of the assembly diameter of balls. 1. D_0=100 (mm); 2. D_0=125 (mm); 3. D_0=150 (mm); 4. D_0=175 (mm); 5. D_0=200 (mm); 6. D_0=250 (mm).

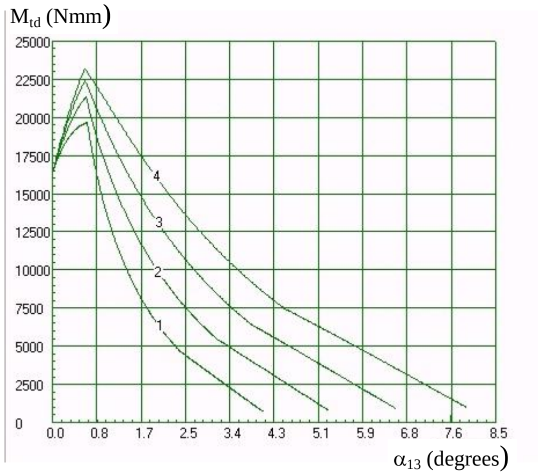

Fig. 10. Variation of torque for different values of the balls' diameter 1. d_b=8 (mm); 2. d_b=12 (mm); 3. d_b=16 (mm); 4. d_b=20 (mm).

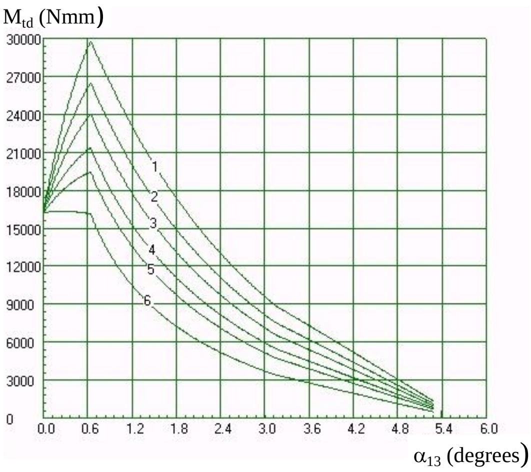

Fig. 11. Variation of torque for different values of arc compression during assembly. 1. δ_1=1 (mm), c=86 (N/mm); 2. δ_1=1.25 (mm), c=69 (N/mm); 3. δ_1=1.5 (mm), c=57 (N/mm); 4. δ_1=2 (mm), c=43 (N/mm); 5. δ_1=2.5 (mm), c=34 (N/mm); 6. δ_1=5 (mm), c=17 (N/mm).

3) The torque variation, M_{td}, depending on the initial deformation of the spring δ_1, by maintaining constant of the pressure force of the spring, is presented in Fig. 11. The torque, M_{tdmax}, decreases with the increase of the assembly deformation of the spring, and at higher values of the initial deformation of the spring, this torque continuously decreases, leading to an increased sensitivity to disengaging, of the clutch (see curve 6, from Fig. 11).

4) The variation of torque, M_{td}, depending on the angle of the active profile of clutch, α_0, is graphically presented in Fig. 12. The torque, M_{tdmax}, decreases with the increasing of angle of the active profile of the clutch, α_0, and to the small values of the angle α_0 (see curves 1 ... 3), the angle α_2 has a relatively high value and leads to a linear variation of torque during the third stage of the disengaging process. The shape of variation curves clearly shows the three stages of the disengaging process from the axial plane and relative rotation angles between the semi-clutches at which takes place the transition from

one stage to another.

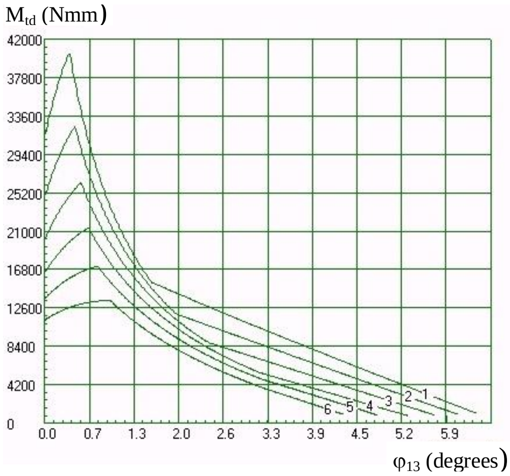

Fig. 12. Variation of torque for different values of angle of the active rabbet profile. 1. α_0=30°; 2. α_0=35°; 3. α_0=40°; 4. α_0=45°; 5. α_0=50° and α_2=50°; 6. α_0=55° and α_2=45°.

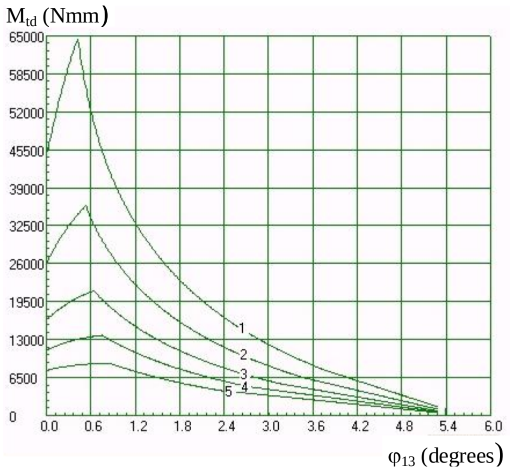

Fig. 13. Variation of torque considering different values of the angle of the first sloped part of the pressure disk 1. α_1=20°, c=69 (N/mm); 2. α_1=25°, c=54 (N/mm); 3. α_1=30°, c=43 (N/mm); 4. α_1=35°, c=36 (N/mm); 5. α_1=40°, c=30 (N/mm).

5) The torque variation, M_{td}, depending on the angle of the first sloped part of pressure disk, α_1, keeping constant the value of torque in the complete engaged working situation by changing the spring stiffness, is graphically shown in Fig. 13. For high values of the angle of the first sloped part of pressure disk (α_1>35º), the ascending variation of torque, M*td*, is greatly reduced, which positively influence the sensibility to disengaging.

IV. Conclusions

The torque value, M_{tdmax}, during the disengaging process decreases with the decrease of the diameter of balls arrangement, D_0, the decrease of the balls diameter, d_b, the decrease of the coefficients of friction μ_0, μ_{01} and μ_{02}, respectively with the increase of the profile angle of active rabbet, α_0, the increase of the angle α_1, of the pressure disk and the increase of the assembly deformation of the arc, δ_1. The angle α_2 affects only the manner to decrease of the torque, but does not influence the value of the maximum torque transmitted by the clutch. The friction coefficients affect in a minor degree the value of the torque transmitted by the clutch during the disengaging process [6].

From the analysis of presented diagrams results that this type of clutch can transmit high torques and by the appropriate selection of the values of some constructive parameters, there can be obtained solutions of safety clutches that to ensure a high sensitivity to disengaging, which would lead to the increase of the performances of these types of safety clutches.

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