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# TORQUE TRANSMITTED BY SAFETY CLUTCHES WITH BALLS AND SPHERICAL RABBETS RADIAL DISPOSED

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***Abstract*—**Safety clutches with balls are a viable solution to protect the transmission against overloads that could occur as a result of some abnormalities in functioning or as a result of incorrect manoeuvres performed by the machine operator. The most widely used active rabbets for safety clutches with balls have a trapezoidal shape, tapered, cylindrical and rarely spherical because it requires a pretentious technology.

***Keywords*—**safety clutch with balls, spherical rabbets radially disposed, description, variation of torque in engaged situation

## I. INTRODUCTION

THE safety clutches integrated in transmissions are able to transmit a controlled torque between the connected elements in order to provide the protection for the transmission and to avoid dangerous overloads determined by malfunctions or by the operator. At the present development stage of the technique and technology, the trend in the industry is to design and incorporate as much automation in the production process. Machines and equipments become more accurate and require a high degree of execution precision. They are becoming faster and more rigid to withstand dynamic loading needed to increase the ability and productivity for the machine [1]-[3]. Within an automated production process, the machine deterioration, and consequently the production process stopping and the machine repairing become very costly [4], [5]. The conclusion reached by many companies is that an insurance, relatively inexpensive, against machine damage at overloads consists of the incorporation of a reliable safety clutch in transmission [2].

The safety clutches integrated in transmissions are able to transmit a controlled torque, between the connected elements, in order to provide the protection for the transmission and to avoid dangerous overloads determined by malfunctions or by the operator [6].

The safety clutches with ball used in the technique can take various forms of active rabbets, with their arrangement in frontal or radial manner, depending on the available gauge. The most used forms of active rabbets are trapezoidal, tapered, cylindrical or spherical. Unlike the other forms of active rabbets [2], [6]-[9], where the contact between the ball and active rabbet is punctiform or linear, the spherical active rabbets have the advantage that both in the complete engaged working situation and during the coupling process, the ball comes in contact with this on a surface and it reduces significantly the pressure that appears as a result of shock.

This paper presents a constructive solution of safety clutch with balls and spherical active rabbets radially disposed; the active rabbets are continued by channels with circular section that follow the whole contour of the semi-clutch and guide both the balls in the disengagement process and in re-coupling process. The aim of the paper is to analyze the variation of the torque transmitted by the clutch in the complete engaged working situation.

## II. DESCRIPTION OF SAFETY CLUTCH

The safety clutch with balls and spherical rabbets radially disposed with pressure system based on pressure plate is presented in Fig. 1 [3], [10] for complete engaged working situation. The active rabbet profile is formed by two arcs: the first radius is equal to the ball radius, the second radius of low value makes the connection with the groove of balls guiding from the exterior surface of the semi-clutch 3. The balls 2 are arranged, on one hand, in the spherical rabbet of the semi-clutch 3 and on the other hand, in the cylindrical hole of the semi-clutch 1 assembled by means of flange screws 9.

The pressure plate 4 is centered both on the flange 9 and on the semi-clutch 1, on the cylindrical part of lower diameter, the centering being achieved by sliding fits. The role of the plate 4 is to press the balls to keep them into the spherical rabbets of the semi-clutch 3; this plate has on the inside two parts inclined at different angles; the first part having both the length and the inclination angle lower, and the second part having the length and the inclination angle higher.

The pressure force exerted on the pressure plate 4 – due to the compression cylindrical spring 5 – is adjusted by means of the grooved nut 7, through the flange 6, secured against dismantle with safety washer 8.

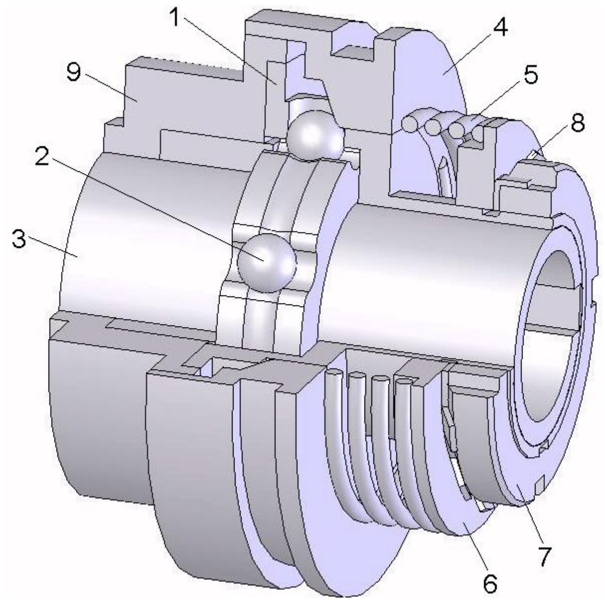


Fig. 1. Complete engaged clutch

The main advantages of this type of clutch are [3]: increasing the load transmission capacity in complete engaged operating situation by increasing the pressure force, as a result of the contact on surface between the balls and the active rabbets; maintaining a narrow range of values of torque for that the disengagement process starts and the increasing of clutch durability by keeping the initial state of the contact surfaces of the active rabbets; it is taken into consideration the fact that at the end of the re-coupling process, the contact occurs on a spherical surface and not on a point or on a line.

In the Fig. 2 [3], [10], it presents the longitudinal section (Fig. 2, a) and the cross section (Fig. 2, b), of the safety clutch with balls and spherical rabbets radially disposed and pressure plate.

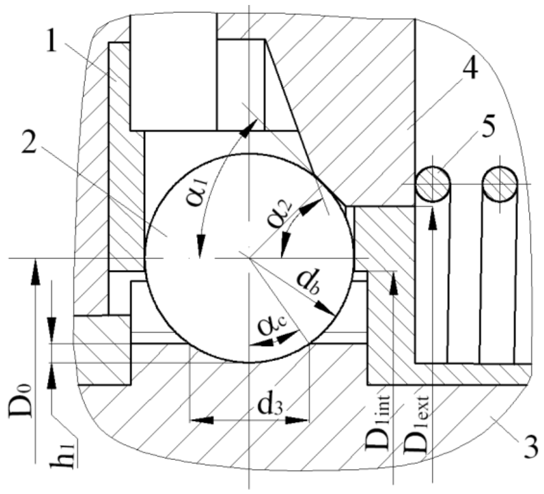
The notations used in this figure have the following significance and values [3], [10]: $d_b$=8...20 (mm) – the diameter of ball; $D_0$=(3...5)d – the diameter of balls arrangement; d – shaft diameter; $\alpha_0$=30°...60° – the angle of the active rabbet profile; r=2...6 (mm) – the rounding radius of the active rabbet profile to the outer circle; $h_1$=1...3 (mm) – the depth of the circular channel; $d_2$ – the distance between the centres of rounding radius of the two sides of a rabbet (this value results from calculus); $\alpha_1$=20°...40° – the angle of the first inclined part of the pressure plate profile, corresponding to the first disengagement stage; $\alpha_2$=45°...75° – the angle of the second inclined part of the pressure plate profile corresponding to the second disengagement stage; h – the depth of penetration of the ball into the active rabbet, determined by Eq. (1); $\gamma_3$ – the angle that subtends the active rabbet profile, determined by Eq. (2).

$$\mathbf{h}=\frac{\mathbf{D_0}}{2}\left(\frac{1}{\cos(\gamma_3/2)}-1\right)-\frac{\mathbf{d_b}}{2}\left(\frac{\sin\alpha_0}{\cos(\gamma_3/2)}-1\right)-\frac{\mathbf{r}\sin\alpha_0}{\cos(\gamma_3/2)} \quad (1)$$

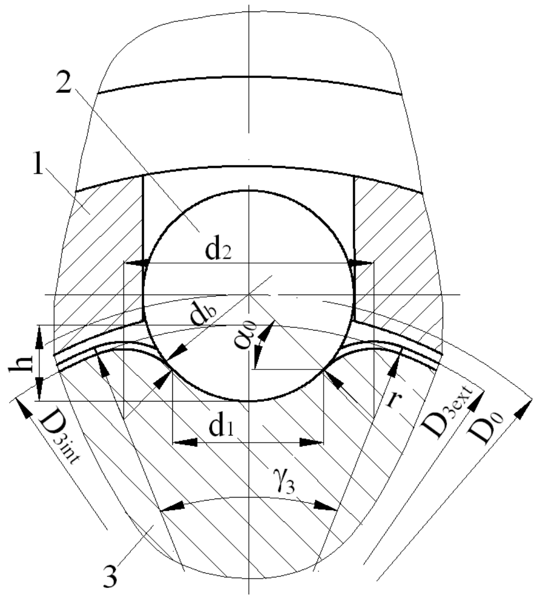
$$\gamma_3=2\tan^{-1}\frac{(\mathbf{d_b}+2\mathbf{r})\cos\alpha_0}{\mathbf{D_0}-(\mathbf{d_b}+2\mathbf{r})\sin\alpha_0}\,. \quad (2)$$

## III. THE ENGAGED WORKING SITUATION

The complete engaged working situation, for this type of clutch, is analyzed considering the limit situation, before the commencement of disengagement process, when the displace tendency of balls appears and therefore frictional forces between the coupling elements occur.



a

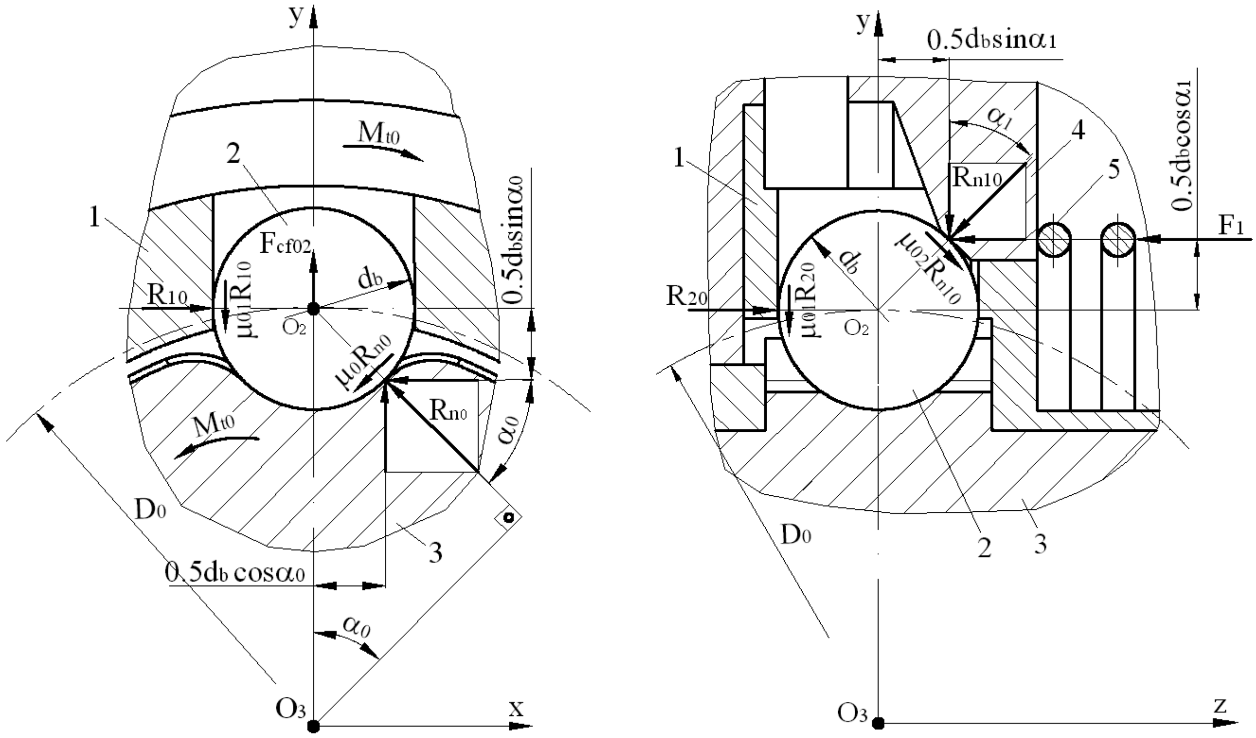


b

Fig. 2. Longitudinal section (a) and cross section (b)

The Fig. 3 presents the partial front section through the model of the safety clutch with balls and spherical rabbets radially disposed, with pressure plate (Fig. 3, a) respectively, a partial longitudinal section (Fig. 3 ,b), in the direction of pressure plate action.

The calculation assumptions adopted for this clutch take into account the following aspects [3], [11], [12]:
1) the complete engaged working situation is analyzed for the starting limit of the disengagement process, when also the frictional forces occur; these forces oppose the movement of active elements of the clutch; corresponding to this situation, the clutch model also includes the friction forces acting on one ball from the clutch;
2) it is also taken into consideration the centrifugal force acting on the ball;
3) there are considered different friction coefficients between the ball and semi-clutch 3, between the ball and the semi-clutch 1, respectively between the ball and the pressure plate 4;
4) the force from the spring centrally disposed is equally distributed on the z balls of the clutch.




a b

Fig. 3. Clutch model for the complete engaged working. a – frontal section; b – longitudinal section

TABLE I
EQUILIBRIUM EQUATIONS

| |
|---|
| $\sum \overline{F_x} = 0: \ R_{10} - R_{n0}(\cos\alpha_0 + \mu_0 \sin\alpha_0) = 0$; $\alpha_0$=30º...60º, the angle of the active rabbet profile |
| $\sum \overline{F_y} = 0: R_{n0}(\sin\alpha_0 - \mu_0\cos\alpha_0) - \mu_{01}R_{10} - R_{n10}(\cos\alpha_1 + \mu_{02}\sin\alpha_1) - \mu_{01}R_{20} + F_{cf02} = 0$; <br> $\alpha_1$=(20º… 40º), the angle of the first inclined part of the pressure plate profile |
| $\sum \overline{F_z} = 0: \ R_{20} - R_{n10}(\sin\alpha_1 - \mu_{02}\cos\alpha_1) = 0$ |
| $\sum \overline{F_z} = 0: \ R_{n10}(\sin\alpha_1 - \mu_{02}\cos\alpha_1) - F_1 = 0$, <br> $F_1 = F_a / z = c\delta_1$, represents the pressure force of the spring corresponding to one ball <br> $F_a$ – spring force; z – the numbers of balls; c – the spring stiffness, in (N/mm); $\delta_1$ – the initial deformation of the spring, in (mm) |
| $\sum \overline{M_{O3}} = 0: \ M_{t0} - zR_{n0}\frac{D_0}{2}\cos\alpha_0 - z\mu_0 R_{n0}\left(\frac{D_0}{2}\sin\alpha_0 - \frac{d_b}{2}\right) = 0$, <br> $D_0 = (3...5)d$, the diameter of arrangement balls <br> $d_b = 8...20$ (mm), the diameter of ball |

The relationships for the calculation of the torque transmitted by the clutch in the complete engaged process $M_{t0}$ and of the reaction forces among the active elements of the clutch are obtained by solving the equilibrium equations, presented by Table I, for the balls, the pressure plate 4 and the semi-clutch 3. The coefficient of static friction $\mu_0$ is considered between the balls and the semi-clutch 3, $\mu_{01}$ between the balls and the semi-clutch 1, and $\mu_{02}$ between the balls and the pressure plate 4.

From solving the system of equations presented by Table I, there result the determination expressions of the normal reaction $R_{n0}$ and of the torque $M_{t0}$ transmitted by the clutch in the complete engaged working situation, expressions presented in Table II.

To highlight the influence of the structural and functional parameters of the clutch on the normal reaction and on the torque transmitted by the clutch in the complete engaged working situation, a computer program was developed, program whose main menu is presented by Fig. 4.

TABLE II
DETERMINATION RELATIONS OF REACTION $R_{N0}$ AND OF THE TORQUE $M_{T0}$

$$R_{n0} = F_1 A_{20}\left(A_{10} - k\right)$$

$k = 0.05...0.08$ – the proportionality factor of the centrifugal force relative to the assembly force of the spring; $A_{10}$, respectively $A_{20}$,- dimensionless sizes determined by relations:

$$A_{10} = \frac{\cos\left(\alpha_1 - \varphi_{01} - \varphi_{02}\right)}{\cos\varphi_{01}\sin\left(\alpha_1 - \varphi_{02}\right)}\ ;\quad A_{20} = \frac{\cos\varphi_0 \cos\varphi_{01}}{\sin\left(\alpha_0 - \varphi_0 - \varphi_{01}\right)}\ ;$$

$\varphi_0 = \operatorname{arctg}\mu_0$ , $\varphi_{01} = \operatorname{arctg}\mu_{01}$ , represent the angles of static friction, corresponding to the static friction coefficients $\mu_0$, $\mu_{01}$ respectively $\mu_{02}$.

$$M_{t0} = z\frac{F_1}{2}A_{20}\left(A_{10} - k\right)\left[D_0\cos\alpha_0 + \mu_0\left(D_0\sin\alpha_0 - d_b\right)\right].$$

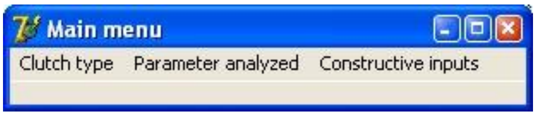


Fig. 4. Main menu

The program was conceived so that to allow the analysis of more safety clutches, namely the safety clutches with balls radially disposed and with spherical rabbets, with spherical rabbets and pressure plate or with rabbets with balls, as in Fig. 5.

Fig. 5. Selection of the clutch type

The program allows the analysis of complete engaged working situation and the disengagement process, respectively the analysis of the torque and normal reaction, as in Fig. 6.

To highlight the influence of structural and functional parameters of the clutch on torque transmitted by clutch in the complete engaged working situation, one ball is considered, the greater number of balls influencing only the value of transmitted torque and not its variation.

Plotting the variation diagram of the parameter selected from Fig. 6, it is achieved in a specific area of this operation [13] depending on the profile angle of the active rabbet $\alpha_0$, measured in degrees.

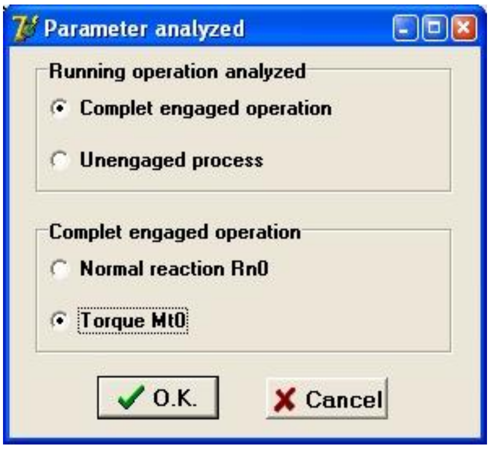


Fig. 6. Selection of the analyzed parameter

1) The influence of diameter of balls arrangement $D_0$ on the torque $M_{t0}$ transmitted by the clutch in the complete engaged working situation is graphically presented by Fig. 7. The significance of curves is the following: 1. $D_0$=100 (mm), 2. $D_0$=125 (mm), $D_0$=150 (mm), $D_0$=175 (mm), $D_0$=200 (mm), $D_0$=250 (mm).

The torque transmitted by clutch in the complete engaged working situation $M_{t0}$ increases with the diameter of balls arrangement $D_0$, this increase being more pronounced at low values of the angle of active rabbet profile. The values range of torque $M_{t0}$ decreases with increasing of the angle of active rabbet profile $\alpha_0$. It can be concluded that the torque $M_{t0}$ can be increased by increasing of the diameter $D_0$ or by decreasing of the angle of active rabbet profile $\alpha_0$.

A very important conclusion was presented in [4] and it refers to the fact that modifying the diameter of the balls does not affect in any way the torque transmitted by the clutch, in the complete engaged working situation.

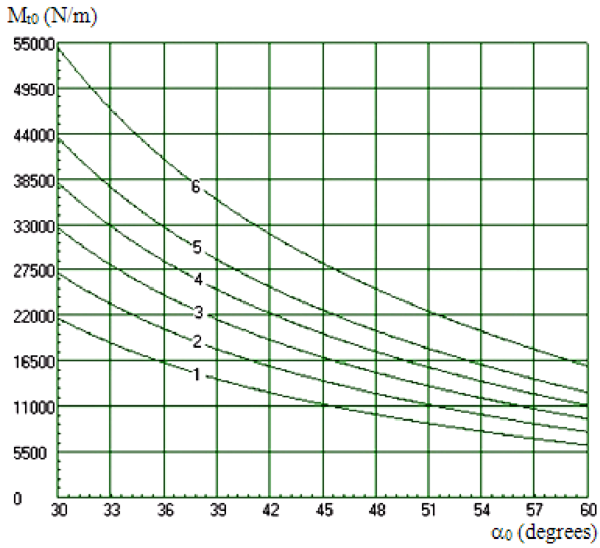



Fig. 7. Variation of torque transmitted by the clutch for different values of the diameter of balls arrangement ($d_b$=12 (mm), $\alpha_1$=30°, r=3 (mm), $\delta_1$=2 (mm), c=43 (N/mm), $h_1$=1.5 (mm), $\mu_0$=0.06, $\mu_1$=$\mu_2$=0.08).

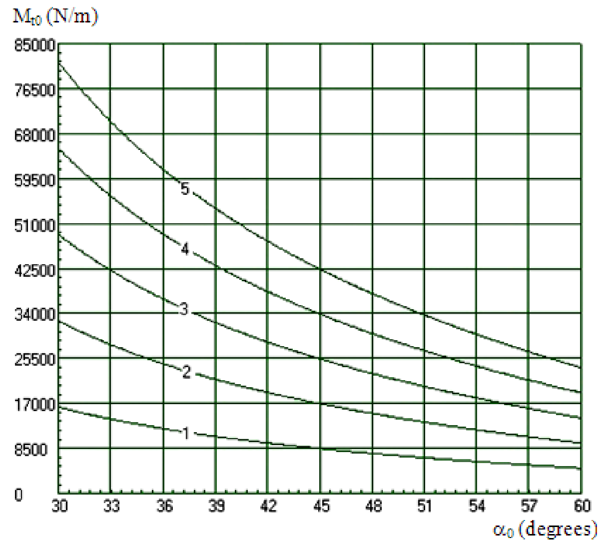



Fig. 8. Variation of torque transmitted by the clutch for different values of arc compression during assembly ($D_0$=150 (mm), $d_b$=12 (mm), $\alpha_1$=30°, r=3 (mm), c=43 (N/mm), $h_1$=1.5 (mm), $\mu_0$=0.06, $\mu_1$=$\mu_2$=0.08)

2) The influence of increasing the pressing force of the spring on the torque transmitted by the safety clutch with balls radially disposed and spherical active rabbets, with pressure plate, considering the increasing of the arc compression during assembly $\delta_1$ and the maintaining the spring stiffness constant is presented in Fig. 8. The significance of curves is as follows: 1. $\delta_1$=1 (mm), 2. $\delta_1$=2 (mm), 3. $\delta_1$=3 (mm), 4. $\delta_1$=4 (mm), 5. $\delta_1$=5 (mm).

The torque transmitted by the clutch in the complete engaged working situation increases to a considerable extent with the amount of spring compression during assembly, especially at low values of the angle of active rabbet profile $\alpha_0$.

As for the variation of the diameter of balls arrangement, the value range of the torque $M_{t0}$ decreases with the increasing of the angle of the active rabbet profile of the clutch $\alpha_0$.

3) The influence of the angle of the first inclined part of the pressure plate $\alpha_1$, on torque transmitted by the clutch in the complete engaged working situation $M_{t0}$ is presented in Fig. 9. To maintain the same force of the spring, once with the modifying of angle $\alpha_1$, the spring stiffness of pressing the balls is modified too. The displayed curves are plotted considering the following parameter values: 1. $\alpha_1$=20°, c=69 (N/mm), 2. $\alpha_1$=25°, c=54 (N/mm), 3. $\alpha_1$=30°, c=43 (N/mm), 4. $\alpha_1$=35°, c=36 (N/mm), 5. $\alpha_1$=40°, c=30 (N/mm).

The torque decreases significantly with the increasing of contact angle between the ball and the first inclined part of the pressure plate $\alpha_1$, and it has high values for low values of the angle of active rabbet profile of the clutch $\alpha_0$. The reduction ratio of the transmitted torque is higher at low values of angles $\alpha_1$, respectively this ratio is less at high values of the same angle.

4) The influence of friction coefficient $\mu_0$ on the torque $M_{t0}$ is graphically represented in Fig. 10, for the maintaining at constant value the friction coefficient $\mu_{01}$ and $\mu_{02}$. The significance of the plotted curves is the following: 1. $\mu_0$=0.06, 2. $\mu_0$=0.08, 3. $\mu_0$=0.1, 4. $\mu_0$=0.12

The increasing of friction coefficient $\mu_0$, between the balls and the spherical active rabbets, leads to small extent to the increase of torque transmitted by clutch in the complete engaged working situation, the most significant increase occurs especially at low values of angle $\alpha_0$.

5) The influence of the friction coefficients $\mu_{01}$ and $\mu_{02}$ is graphically presented in Fig. 11, considering the maintaining to a constant value of friction coefficient $\mu_0$. The curves have the following significance: 1. $\mu_1$=$\mu_2$=0.08, 2. $\mu_1$=$\mu_2$=0.1, 3. $\mu_1$=$\mu_2$=0.12

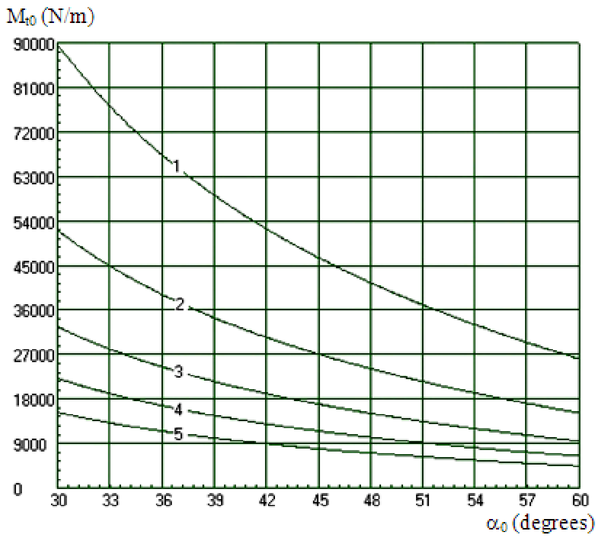



Fig. 9. Variation of torque transmitted by the clutch considering different values of the angle of the first inclined part of the pressure plate ($D_0$=150 (mm), $d_b$=12 (mm), r=3 (mm), $h_1$=1.5 (mm), $\mu_0$=0.06, $\mu_1$=$\mu_2$=0.08).

The increasing of friction coefficient $\mu_{01}$, between the balls and the cylindrical rabbets and the increase of friction coefficient between the balls and pressure plate $\mu_{02}$, lead to the increase to a greater extent of the torque transmitted by clutch in the complete engaged working situation, compared with its increase due to increase of friction coefficient $\mu_0$.

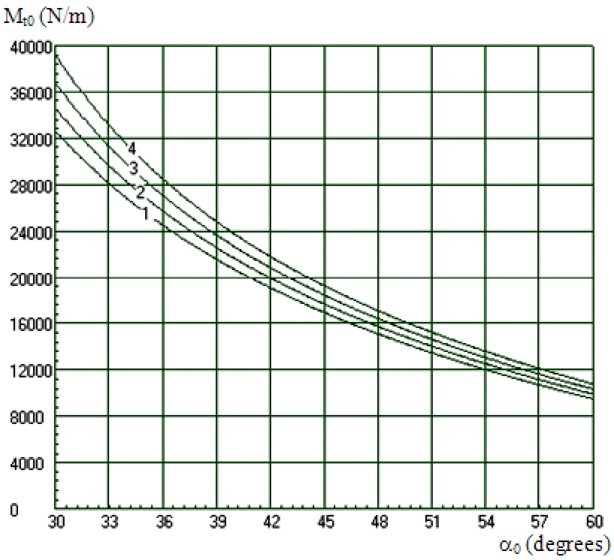



Fig. 10. Variation of torque transmitted by the clutch for different friction coefficient values $\mu_0$ ($D_0$=150 (mm), $d_b$=12 (mm), $\alpha_1$=30°, r=3 (mm), c=43 (N/mm), $h_1$=1.5 (mm), $\mu_1$=$\mu_2$=0.08).

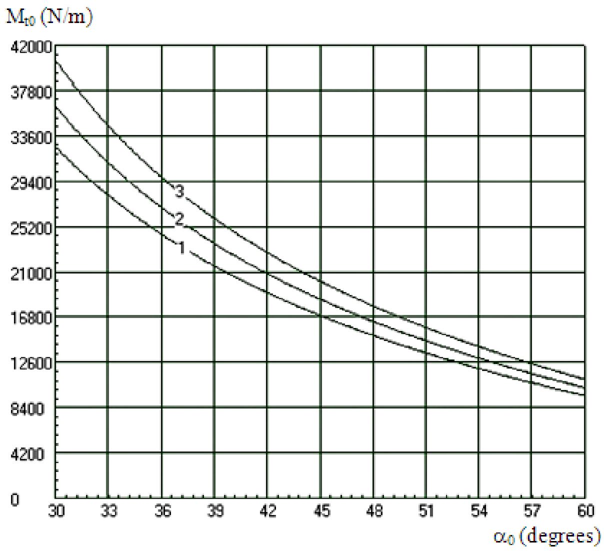



Fig. 11. Variation of torque transmitted by the clutch depending on the friction coefficients $\mu_{01}$ and $\mu_{02}$ ($D_0$=150 (mm), $d_b$=12 (mm), $\alpha_1$=30°, r=3 (mm), c=43 (N/mm), $h_1$=1.5 (mm), $\mu_0$=0.06).

The increase is higher, especially at low values of the angle of active rabbet profile $\alpha_0$.

## IV. CONCLUSION

In conclusion, the value of torque transmitted by clutch in the complete engaged working situation $M_{t0}$ increases with the increasing of the diameter of balls arrangement with the increasing of the diameter of balls arrangement the balls, the spring force and the friction coefficients between the balls and active rabbet, between the balls and retention rabbet and between the balls and the pressure plate, respectively by reducing the profile angle of active rabbet $\alpha_0$ and the contact angle of ball with the first inclined part of the pressure plate $\alpha_1$.

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