Effects of Some Differences Of The Sizes of Ball Threads on The Operation Of The Thread

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Abstract

Little geometric deviation of the thread groove on the nut or pin could cause the deterioration of any ball thread's elements. Effects of alteration in connecting angle and action angle have been calculated and tested with measurement of well and not well machined ball threaded gears. A little bit bigger action angle than the nominal one causes ball blocking in the ball returning tubes and in case of outside values of other dimensions the ear of the returning tube can break mainly at extremely heavy load.

1 Introduction

In order to reduce the wear and to increase then efficiency threads are used in some gears in which there are balls between the nut and the pin threads. For these threaded machines grooves of the same profile cross-section are developed both on the nut and the pin for the balls. The balls do planetary motion along the spiral in the thread, so in addition to their motion component along the longitudinal axis of the thread they work similarly to the balls of the rolling bearings. Also the physical behaviour of the balls and the bearing can be approached according to the theories developed for the ball bearings. Compared to the bearings a fundamental difference is that the balls in the path groove do not return always to the same position but doing a progressive motion as well. In the thread they roll from the start of the thread towards the end of the thread so they enter the grooves and leave them. The aim of the performed tests is to analyse these entering and leaving conditions in function of some geometric characteristics and the load.

For the examination we made calculations regarding to the effects of some sizes of the thread on the motion of the balls, primarily analysing what size differences can cause significant force on the balls for entering and leaving the threads. In order to confirm the calculations, measurements were performed to determine the impressing force and the thread torque together for gears of different thread profiles.

2 Parts and operation of the ball thread

The ball thread is a part of a gear but it can be unambiguously separated from the gear and consists of the following items:

- pin
- nut
- balls
- ball returning tube
- its fixture

The pin and the nut have the same lead and generally the same profile shape. In this case the angles connecting to the profile of the balls are the same as well that is for these threads the angle of action in the unloaded thread is the same as the connecting angle. In the thread the balls align close and generally contact to each other. The start of the thread is really where the balls enter the thread. This place is the bore made on the nut where the ball returning tube is connected. The other end of this tube is at the end of the nut and it returns the leaving balls from there to the start of the thread. Leaving of the balls are assisted by the so-called ears on the tubes which really inhibit the balls from over-rolling and they take them off. The start and end of the thread can be naturally interchanged depending on the rotation direction of the pin and the nut. For small load and proper geometric form of the thread the stress on the returning tube and its ear is has no account and the tube can properly guide the balls between the ends of the thread.

Increasing the load and in case of certain profile forms the forces affecting the balls can expose the ball returning tube and its ear to a significant load which can lead to the deterioration of the thread.

The profile forming of the thread has an important role in the operation of the thread. The profile of the thread has a circular cross-section, the radius of its manufacturing is larger than that of the ball and the centre of manufacturing is shifted away from the axis of the profile. This shift provides for the appropriate engagement between the thread and the ball for all occurring thread loads. The fit between the ball and the thread profile is shown in the Fig. 1 on which the pin and nut threads are made with different profiles.

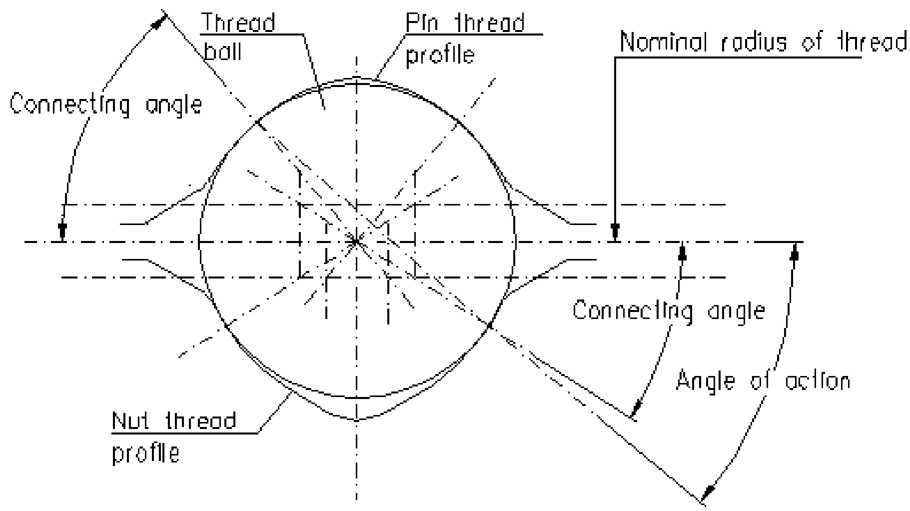

Figure 1: Perpendicular section of the thread: the thread profile

The work of the thread is to transform the torque to a axial force. This transformation implements in the connection of the thread balls along the nut and pin profiles. Since in the thread, at the contact point of the balls and the profile, the profile tangent includes an acute angle with the central line of the thread at any point of the profile arc. The connection force of the balls and the arc always has a component, which forces the connecting places of the balls toward the edge of the profile. This coercing force increases with loading the thread and due to it both the connecting angle on the pin and the nut as well as the angle of the action lines of the forces on the ball, the action angle decrease.

The elastic deformation developing on the contacting surface of the balls and the profile allows the action angle to change. On the basis of this deformation the change in the action angle can be determined as follows according to Molnr-Dr. Varga[1].

Actual action angle:

$$\alpha = \arcsin\left[\frac{\sin\alpha_0 + \frac{\delta_a}{A}}{\sqrt{\cos^2\alpha_0 + \left(\sin\alpha_0 + \frac{\delta_a}{A}\right)^2}}\right] \tag{1}$$

In load free case the theoretical action angle is as follows:

$$\alpha_0 = \arccos\left(1 - \frac{H_t}{2A}\right) \tag{2}$$

Distance between the trajectory centres:

$$A = (f_k + f_b - 1)d_g \tag{3}$$

Actual elastic deformation:

$$\delta_a = A' - A \tag{4}$$

Distance between the centres changed under the effect of deformation:

$$A' = \sqrt{A^2 \cos^2 \alpha_0 + (A \sin \alpha_0 + \delta_a^2)} \tag{5}$$

Relation between the deformation of action direction and the axial deformation:

$$\delta = \sqrt{A^2 \cos^2 \alpha_0 + (A \sin \alpha_0 + \delta_a^2)} - A \tag{6}$$

Osculation of the balls and trajectories:

$$f_k = \frac{r_k}{d_g} \tag{7}$$

$$f_b = \frac{r_b}{d_g} \tag{8}$$

Axial load:

$$F_a = zF_g \sin \alpha \cos \varphi \tag{9}$$

Load of a ball:

$$F_g = K_n \delta^n \tag{10}$$

Constant depending on the contacting conditions:

$$K_n = \left[\frac{1}{\left(\frac{1}{K_b}\right)^{\frac{1}{n}} + \left(\frac{1}{K_k}\right)^{\frac{1}{n}}} \right]^n \tag{11}$$

n is the exponent depending on the contacting points, its value relating on the ball bearings:

$$n = 3/2 \tag{12}$$

Contacting constant relating to the pin:

$$K_b = 2.14 \cdot 10^4 \frac{1}{\sqrt{\sum \rho_b \delta_b^{*3}}} \tag{13}$$

Contacting constant relating to the nut:

$$K_k = 2.14 \cdot 10^4 \frac{1}{\sqrt{\sum \rho_k \delta_k^{*3}}} \tag{14}$$

Sum of the main incurvations on the pin:

$$\sum \rho_b = \frac{1}{d_g} \left[4 + \frac{2\gamma}{1 - \gamma} - \frac{1}{f_b} \right] \tag{15}$$

Sum of the main incurvations on the pin:

$$\sum \rho_k = \frac{1}{d_g} \left[4 + \frac{2\gamma}{1 - \gamma} - \frac{1}{f_k} \right] \tag{16}$$

Intermediate constant:

$$\gamma = \frac{d_g \cos\alpha}{d_m} \tag{17}$$

Curvature relation: on the contacting point between the pin and the ball:

$$F(\rho)_b = \frac{\frac{2\gamma}{1-\gamma} + \frac{1}{f_b}}{4 + \frac{2\gamma}{1-\gamma} - \frac{1}{f_b}} \tag{18}$$

on the contacting point between the nut and the ball:

$$F(\rho)_k = \frac{\frac{2\gamma}{1-\gamma} + \frac{1}{f_k}}{4 + \frac{2\gamma}{1-\gamma} - \frac{1}{f_k}} \tag{19}$$

Elastic deformation at the pin:

$$\delta_b = 0.013 \cdot \delta^* \sqrt[3]{F_g^2 \rho_b} \tag{20}$$

at the nut:

$$\delta_b = 0.013 \cdot \delta^* \sqrt[3]{F_g^2 \rho_k} \tag{21}$$

The function $\delta^* = f(F_g^2 \rho_k)$ on the basis of the *tests of MGM* on Figure 2:[2]
Small semi-axis of the contacting ellipse:

$$b = 0.05101 \cdot b^* \sqrt[3]{\frac{F_g}{\sum \rho}} \tag{22}$$

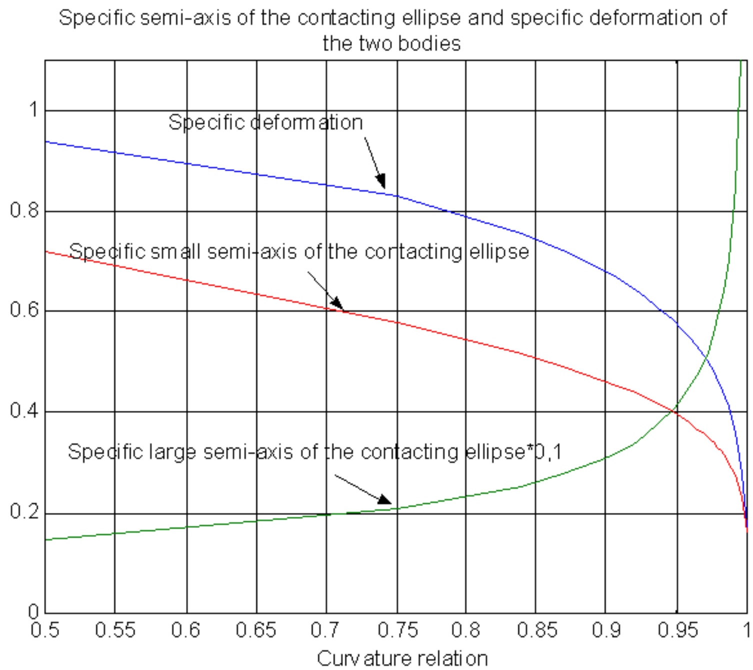

Figure 2: Specific data of the contact between the ball and the ball path

On the basis of the above relations and the diagrams of the Fig. 2 the change in the actual action angle in the function of the load.

The angle of action increases digressively in the function of the load and in case of the well-dimensioned thread profile the edge of the depression ellipse cannot reach the boundary of the profile. However if the load exceeds the dimensioning limit the pitch changes or if the connecting angle given from the manufacturing dimensions increases on the nut the edge of depression can reach the edge of the travelling profile of the nut thread. In this case the surface load both on the ball and the path do not develop according to the Hertz voltage distribution and the proportional elasticity. The laying surface doesn't increase according to the earlier used relations, the load of the ball increases significantly and the edge of the profile depresses in the ball. This large surface load will increase the axial displacement of the thread profiles and causes a bottleneck in the thread.

3 Motion of the balls from the end of the thread to the start of the thread

The motion of the balls in the thread was discussed earlier. It was stated there that in case of improper profile shape the balls could come to the edge of the nut or pin thread. So for larger loads the deformation of the balls increases significantly. Because of the increase of the element's deformation the axial play of the thread (the longitudinal displacement of the pin and the nut compared to each other) will be larger as well than that of belonging to the normal thread. Because of the axial "shearing" of the thread profile the unloaded balls are able to enter the thread only under the effect of a large force. This force effect closes on the balls in the thread through the balls blocking in the ball returning tubes and if a ball is just at the leaving ear for blocking the ear is loaded by a significant component of the blocking force. If the ball returning tubes are able to go up as well the blocking force lifts the tubes and leaving and entering the thread will occur really at the same time as it can be seen on the figure and then the larger force acts on the ear. The blocking force is increased on by the displacement of the bores of the ball returning tube from the thread profile.

The blocking position of the balls can be determined on the basis of the wear scheme of the examined used returning tube.

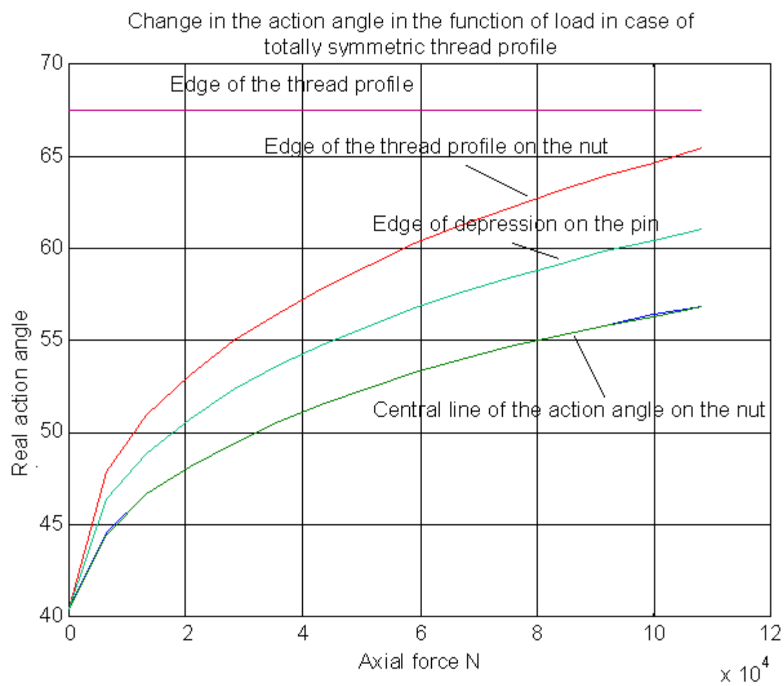

Figure 3: Change in the action angle in the function of load in case of totally symmetric thread profile

Figure 5 shows the lying of the balls and leave and enter of the balls. The ball laying shown by the picture is the same as the wear scheme taken for some shelly worn ball returning tubes. It can be concluded that the shelly-wear form formed in the ball returning tubes due to the improper thread machining.

Since for large loads or improper profile shapes the balls run on the edge of the thread profile, also the entering ball contacts the edge of the thread first. The effect of this sharp corner - because of the penetration of the bore and the thread - can cause a cut-like stress on the balls, which can be observed very well in these used gears.

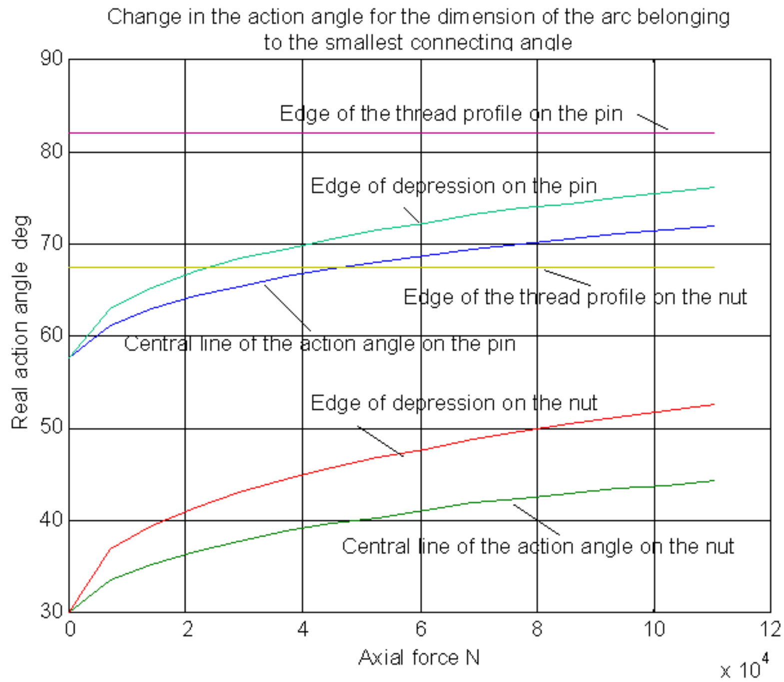

Figure 4: Change in the action angle for a nut thread profile having decreased connecting angle

4 Examination of the effect of the profile radius on the operation of the thread with measurements

The effect of the thread profile made with improper geometric dimensions on the operation of the gear was examined by measuring the stress acting on the ball returning tube. The measurements in the function of the angular displacement of the pin were performed with nuts of different profile radius.

First measurements were performed on a gearbox with a nut thread profile machined to a smaller radius than the nominal size, for small load. It is well visible on Fig. 6 that for entering and leaving of every third ball large ear- stress originated and peak values appeared on the diagram of the driving torque at the same frequency.

The same measurement series was carried out for a gearbox with a nut thread of a nominal arc radius.

Figure 7 shows the pin torque and ear stress diagram of the thread of a nut profile regarded as good taken at the largest load in the function of the displacement. Compared to the earlier narrow thread profile the ear stress is insignificant and despite to the almost double load the periodic character, which could be observed on the earlier function appearing on the torque-curve cannot be seen as well.

The ball returning tube in the gearbox having a nut of a closed profile exposed to a heavy load suffered a set deformation and cut-like damages came into existence on the balls (Fig. 8).

5 Summary

For gears of ball thread the thread-profile requires a high accuracy and strictly dimensioned and checked tolerance fields. During machining the final forming of the arc radius of the thread profiles has subjective manufacturing steps as well. Measuring of radius is complicated, it cannot be mechanised and this process depending on persons and the measurements' results can not be documented. Consequently a radius dimension can form which can differ - although only in a slight degree - from the nominal dimensions. The effect of this difference was shown with the check and measurements carried out with calculations. Both the calculations and the measurements confirm that the discussed differences in the dimensions can cause serious damages in the operation of the thread and high attention should be paid to their check and to the accuracy of manufacturing.

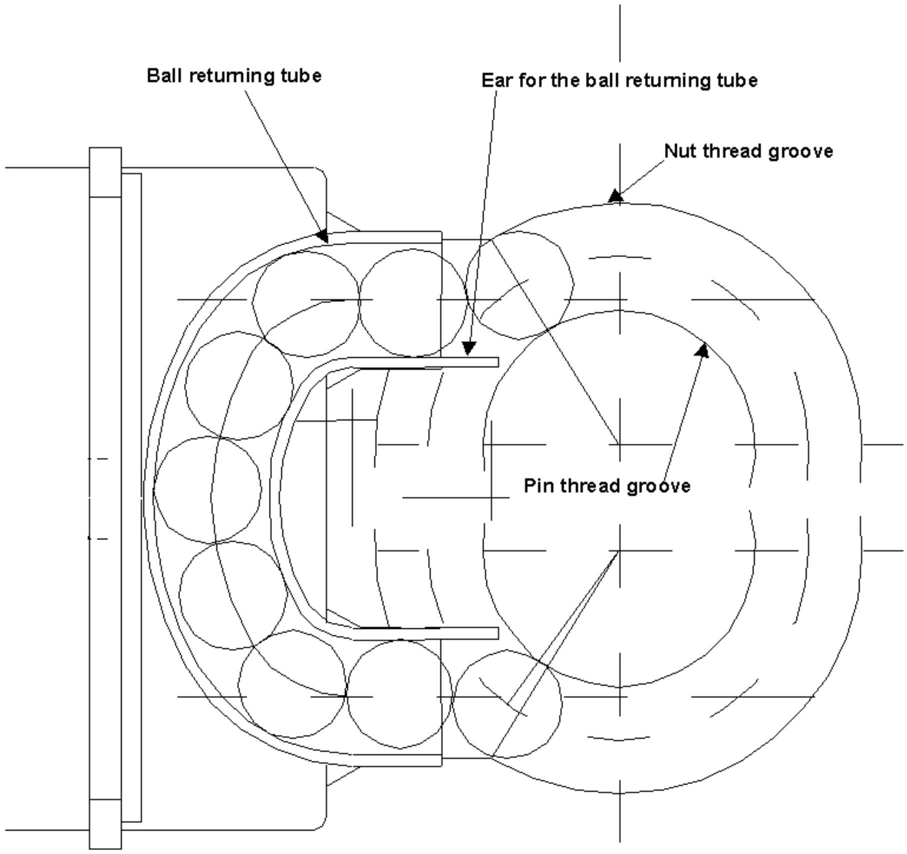

Figure 5: Position of the balls in the ball returning tube in case of blocking

References

[1] Molnr Lszl, dr. Varga Lszl Grdlcsapgyak tervezse, Mszaki Knyvkiad 1977.

[2] MGM 662. sz. Tjkoztat 1975.

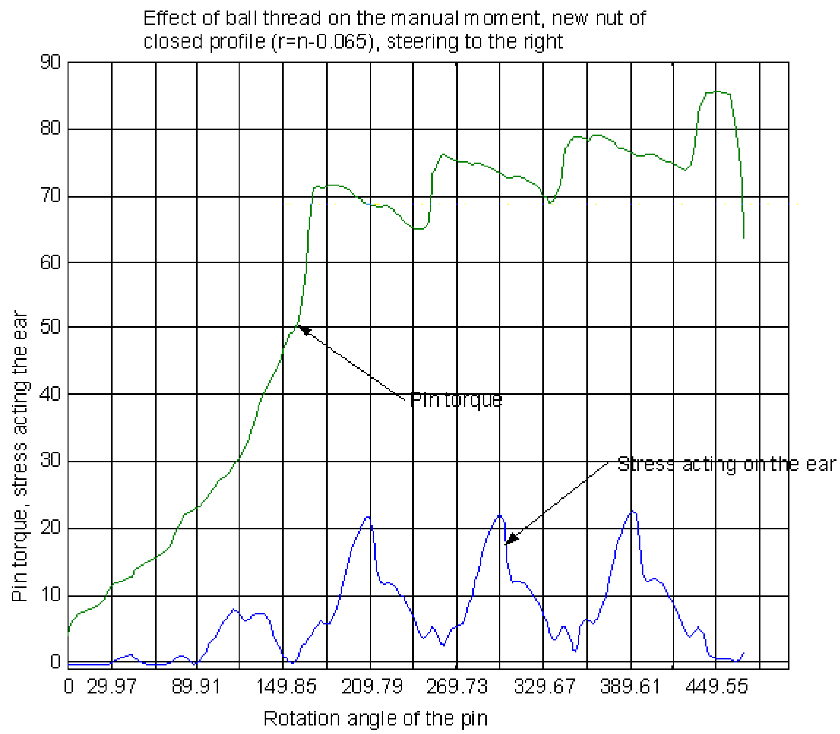

Figure 6: Measurement of a gear having a nut thread profile of larger connecting angle than the nominal one

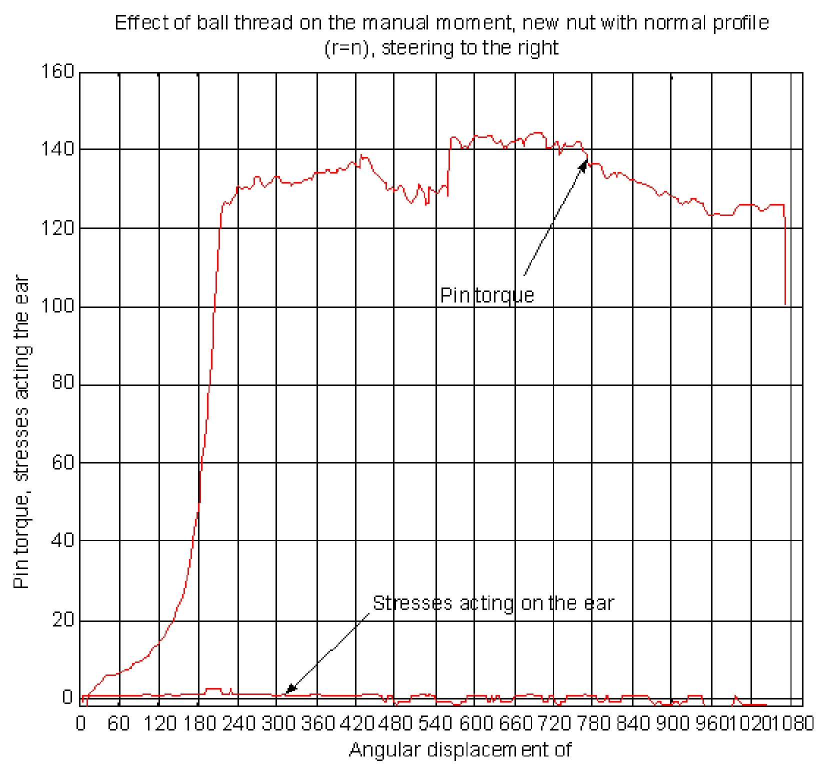

Figure 7: Driving torque and thread stress of a gear having a nut thread profile of larger connecting angle than the nominal one

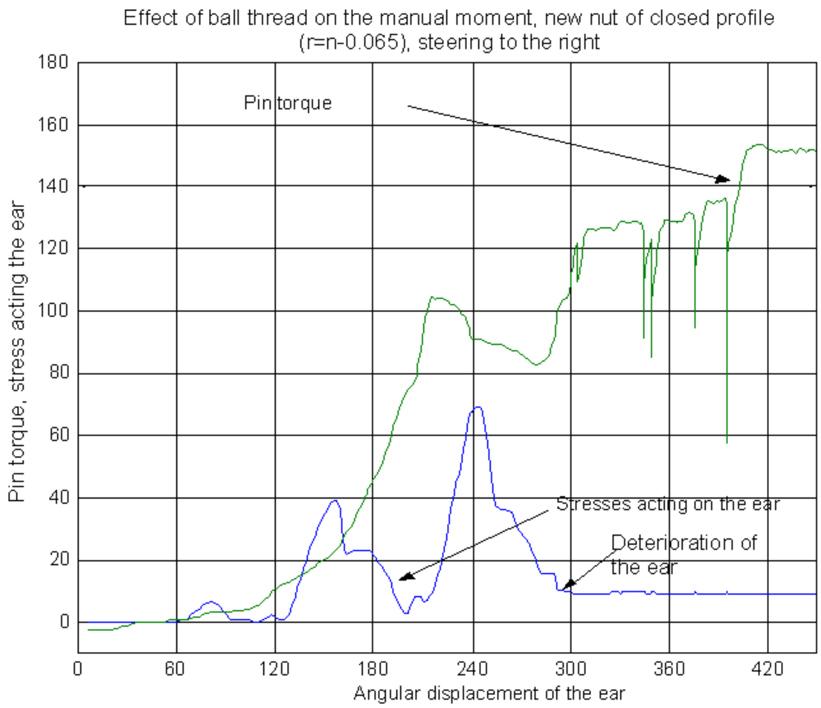

Figure 8: Measuring of the set deformation of the ball returning tube ear and the deterioration of the thread