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ERROR OF THE THREADED SURFACE MINOR DIAMETER DUE TO THE POSITION OF THE THREADING TOOL NOSE

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Abstract: *The threads are surfaces commonly used when demountable joints are necessary. Some of the threading methods involve the use of threading tools on a lathe. The accuracy of the threaded surfaces depends on the positioning of the threading tool relative to the workpiece axial plane. In order to evaluate the influence of the positioning the threading tool nose on some accuracy parameters of the threaded surfaces, a theoretical model was established on the base of geometric considerations. The model highlights the influence of the distance between the threading tool nose and the workpiece axial plane on the value of the threaded surface minor diameter. Since the model does not offer a direct image concerning the intensity of the influence exerted by the threading tool nose position on the value of the threaded surface minor diameter, a power type model was also established considering the initial geometric model. To experimentally investigate the influence exerted by distinct rotations and displacement of the threading tool around and along the axes of a Cartesian coordinate system, a device for controlled changing of the position of the threading tool was designed and achieved. The preliminary experimental research proved the possibilities of using such a device to investigate the influence exerted by the positioning of the threading tool on the parameters specific to a threaded surface.*

Key words: *threaded surfaces, accuracy, threading tool position, geometric model, power type model, experimental device.*

1. INTRODUCTION

To obtain demountable joints, some distinct solutions could be used. One of these solutions is based on the use of threaded surfaces.

As proper machine elements that present threaded surfaces and are used to constitute threaded joints, the screws and nuts are commonly preferred.

The main advantage of the threaded surfaces is their high capacity to be used of thousand times, without needing a high level of professional knowledge during the assembling operations.

From the theoretical point of view, a threaded surface could be obtained by moving a certain profile (triangle, square, arc of circle, etc.) along a spiral trajectory placed on a cylindrical, conical or other type of surface.

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The threaded surfaces or the threads could be classified by considering the measuring system, pitch size, direction of the spiral trajectory, destination, type of surface on which the thread is placed, accuracy, etc.

When the accuracy of a metric cylindrical thread is analyzed, one takes into consideration the values of the major and minor diameters, of the pitch, of the spiral angle, and the thread profile; some of the dimensional parameters were included in the schematically graphical representation from Fig. 1.

There are many ways of obtaining threaded surfaces. Thus, there are processing methods in which the threaded surfaces are materialized by cold plastic deformation; on the other hand, the threaded surfaces could be manufactured inclusively by using distinct machining methods which suppose the material removal from the workpiece.

Threaded surfaces could be obtained and finished by turning, milling, by means of the hand threading tools, grinding, lapping, etc.

If in the case of small diameter threaded surfaces especially hand threading tools could be preferred, when

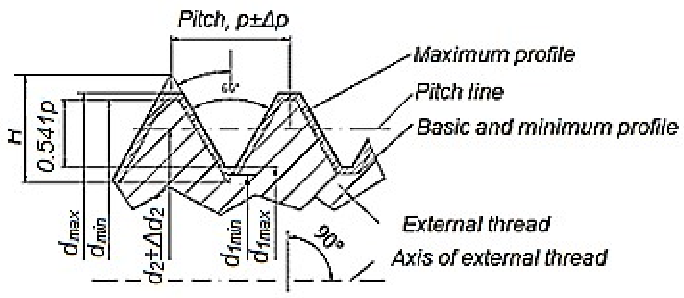

Fig. 1. Main dimensional characteristics of the metric thread profile [8].

a high productivity and accuracy is necessary, the threaded surfaces could be obtained on lathes.

Over the years, the researchers investigated various aspects concerning the accuracy of the threaded surfaces manufactured by distinct machining methods.

Thus, Saotome et al. developed a research concerning the precision of the internal threaded surfaces achieved on stainless steel workpieces [5]. They investigated a machining method based on the use of a vibrating cutting tool on a lathe. The vibration was characterized by a frequency of 20 kHz and an amplitude of 15 μm. The Japanese researchers noticed that the presence of the vibration facilitated the generation of a smooth machined flank surface and that the desired sharp profile could be obtained.

Onisko developed a theoretical research aiming to determine an analytic relation able to highlight the thread profile error as a function of the tangential deviation of the threading tool when the tool has a non-inclined rake surface [3]. In this way, he took also into consideration the evaluation of the angle values, and of the axial and radial deviation of the obtained threaded surface. He concluded that the tangential deviation of the cutting tool nose higher than 200 microns generates deviations of the thread profile higher than the admissible error when the major diameter is of 20–25 mm.

Cheng noticed that when using the geometric analysis of the axial section projection image of the threaded surface, a process of the thread profile distortion could appear and this process may affect the measurements results [1]. He proposed a calculation formula of the thread profile distortion and an adequate compensation algorithm. He established also that the compensation effect could be higher than 85 % in pitch diameter and higher than 70 % in thread angle.

The objective of the research presented in this paper was to evaluate the threaded surface errors generated by the threading tool position relative to the axial plane of the workpiece trained in a rotation motion.

2. THEORETICAL CONSIDERATIONS

The machining scheme that corresponds to the threading process developed on a lathe by means of threading tools is presented in Fig. 2; the case of machining of an external cylindrical metric thread was considered.

One may see that at each rotation of the workpiece, the threading tool must move along a direction parallel to the workpiece rotation axis with a pitch.

It is known that there are many factors able to exert influence on the machining accuracy of the surfaces obtained by cutting techniques: the state of the

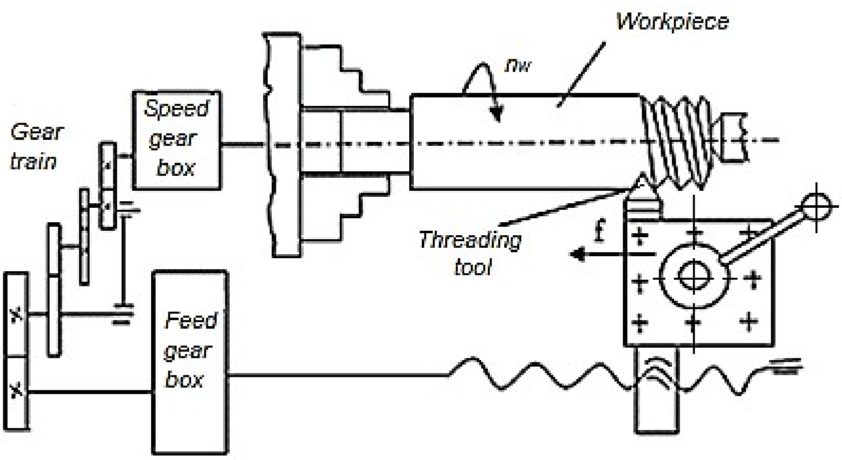

Fig. 2. Machining scheme valid in the case of obtaining threaded surfaces on a lathe.

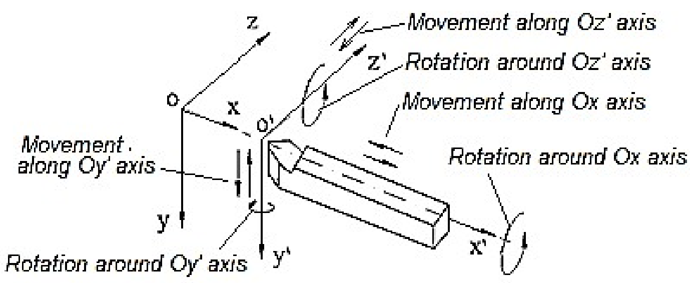

Fig. 3. Considered possibilities of changing the position of the threading tool nose in order to affect the accuracy of the external metric threaded surface.

technological system components, the wear of these components, the extension of certain components under the influence of the heat developed during the machining process, the rigidity of the technological system components, the accuracy of positioning the tool nose relative to the workpiece surfaces, the positioning and clamping the workpiece and the tool in the adequate devices [4, 9], etc.

As it can be seen, there is a certain influence that sometimes could become significant and that is exerted by the tool nose position relative to the workpiece initial surfaces, especially when working on the universal machine tool, in the individual or small series production.

Thus, in the case of obtaining the threaded surface on a lathe, the threading tool nose must be situated in the axial plane of the workpiece rotation axis; from the theoretical point of view, during the thread roughing stage, after the contact of the threading tool nose with the workpiece external surface, a transversal displacement with a distance that corresponds to the thread height is necessary.

Practically, the thread is obtained using many lathe tool strokes, after the adequate positioning of the threading tool for each work stroke.

Due to various reasons, it is possible that during the proper threading process, the tool nose has a position over or under the workpiece axial plane. In this way, a set of possible errors could appear.

As main factors able to affect the correct position of the tool nose relative to the workpiece axial plane, it can consider the accuracy of the positioning and clamping the threading tool into lathe tool holder, the force of clamping the threading tool in the lathe tool holder, etc. A positioning of the threading tool under the workpiece axial plane could be generated inclusively by the main component of the cutting force developed during the threading process developed on the lathe.

In Fig. 3, an additional coordinate system *O'x'y'z'* attached to the threading tool nose could be observed, without the common coordinate system *Oxyz* attached to the machining technological system. Three rotation movements and three rectilinear movements around or along the three axes of a Cartesian coordinate system are possible.

Without the displacement along the *O'z'* axis, all the other rectilinear displacements of the threading tool nose exert influence on the machining accuracy of the threaded surface.

Some of the rectilinear displacements and rotations could exert a higher influence, while the others – a less significant influence. It is of technological interest to have information concerning the influence possible to affect the accuracy of the threaded surface, as there it could be interesting to highlight the cumulated influence of two or more displacements or rotations of the threading tool nose on the accuracy of the threaded surface.

As above-mentioned, the main dimensions of the metric external cylindrical threaded surface are the minor and major diameters, the thread height, the pitch, the angle of the spiral along the workpiece; some of these main dimensions of the metric external threaded surface were highlighted in Fig. 1.

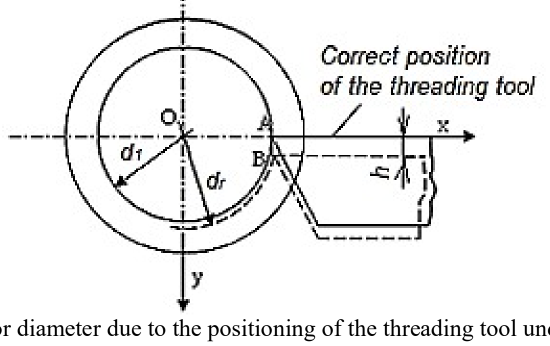

Fig. 4. Error of the minor diameter due to the positioning of the threading tool under the horizontal plane of the workpiece rotation axis.

The main factors able to exert influence on the accuracy of the threaded surface are the followings [4, 9]:

- the dimensions and the shape of the workpiece;
- the positioning and the clamping of the workpiece in the device intended to be used;
- the machine tool accuracy;
- the setting of the threading tool position relative to the workpiece, etc.

In accordance with a theoretical model previously established [6], an incorrect positioning of the threading tool nose relative to the workpiece axial plane has as a main consequence the generation of a profile error ε_{tp} of the thread flank that; in the case of the metric thread, this error could be estimated by means of the relation:

$$\varepsilon_{tp} = \Delta z \cdot \cos 30^{\circ}, \quad (1)$$

where Δz is the difference between the ordinates of the points that have the same abscissa x and are placed on the right line that correspond to the correct thread profile and on the hyperbole arc that corresponds to the real thread profile, respectively, when there is a certain distance h between the tool nose and the workpiece axial plane (the relation (1) was established by considering Δh = 2 mm and a metric thread M48).

Another dimension of the threaded surface that could be affected by the position of the threading tool nose relative to the workpiece axial plane is the threaded surface minor diameter d_1.

Let us suppose that in the case illustrated in Fig. 4, if the threading tool nose is correctly positioned, the interior surface of the thread must have the diameter d_1 (minor diameter).

Due to various factors, it is possible that in the real situation, the threading tool nose could be placed at a distance h under the horizontal plane of the workpiece axis.

In such a situation, instead of the minor diameter d_1 of the threaded surface, a real diameter d_r will by obtained.

When considering that the correct position of the threading tool nose corresponds to the point A in Fig. 4, the real position of the threading tool nose could correspond to the point B. The segment OB from the rectangular triangle OAB is a half of the real minor diameter d_r, and, considering the Pitagora's theorem, one could write:

$$\frac{d_r}{z} = \sqrt{\left(\frac{d_1}{z}\right)^2 + h^2}\ . \quad (2)$$

The error of the minor diameter d_1 will be:

$$\Delta d_1 = d_r - d_1, \quad (3)$$

or taking into consideration the above-written relation:

$$\Delta d_1 = 2\sqrt{\left(\frac{d_1}{z}\right)^2 + h^2} - d_m\ . \quad (4)$$

Since such a theoretical relation does not offer a direct image concerning the intensity of the influence exerted by the distance h on the error Δd_1 of the minor diameter d_1, the values of the minor diameter error Δd_1

Table 1

Values determined for the minor diameter error *Δd₁*, when the distance *h* has values of 0–3.5 mm, (values determined by means of the relation (4), in the case of an external metric thread M48)

h	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5
Δ*d*₁	0	0.0117	0,0469	0,1055	0,1874	0,2925	0,4205	0,5714

can be determined by considering some proper values in the above-written relation.

Thus, let us consider d_1 = 42.587 mm (that corresponds to an external metric thread M48) and distinct values for the distance h. Such values could be, for example, those presented in the Table 1.

The information included in Table 1 was mathematically processed by means of a specialized software based on the use of the least squares method [2]. The software allows the selection of the most adequate mathematical model relative to the introduced information, taking into consideration five such models (polynomial of first and second degree, power type function, exponential function, hyperbolic function).

The selection could be made by means of the Gauss's criterion; the value of the Gauss's criterion is given by the sum of the squares of the differences between the ordinates corresponding to a certain mathematical model and the values of the ordinates introduced in accordance with the initial information. The lower the value of the Gauss's criterion is, the better adequate the selected mathematical model is.

Using the above-mentioned software, the following mathematical model was found as the most adequate relative to the initial information:

$$\Delta d_1 = 0.0464\,h^2 + 0.00096\,h - 0.000228\,, \quad (5)$$

for which the Gauss's criterion has the value $S_G = 3.964904 \cdot 10^{-8}$.

In the machine manufacturing processes, the power type functions are usually preferred due to the fact that such a mathematical function offers a direct and more illustrative information concerning the intensity of the influence exerted by the considered process input factor on the dependent variable. Taking into consideration such an observation, by means of the above mentioned specialized software [2], a power type mathematical model was also established:

$$\Delta d_1 = 0.0880 h^{0.841}\,, \quad (5)$$

the Gauss's criterion having in this case a higher value, S_G = 0.0191837, since the power type function corresponds in a lesser extent to the introduced data.

The value of the exponent attached to the distance h in the power type function shows a strong enough influence exerted by this independent variable on the minor diameter d_1 of the threaded surface.

A graphical representation elaborated on the base of the numerical model (5) could be observed in the Fig. 5.

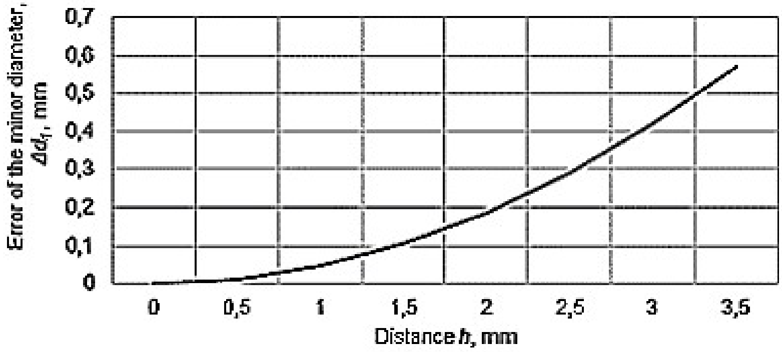

Fig. 5. Influence of the distance Δh on the error of thread minor diameter Δd_1, in accordance with the numerical model (5).

As expected, by the analysis of the numerical model constituted by the relation (5) and of the graphical representation presented in Fig. 5, the error of the minor diameter d_1 will increase when the distance h increases, too.

The value of the exponent attached to the factor Δh in the numerical model defined by the relation (5) offers an image concerning the intensity of the influence exerted by the distance h on the error Δd_1 of the thread minor diameter.

3. DEVICE FOR EXPERIMENTAL REASEARCH OF THE INFLUENCE EXERTED BY THE POZITION OF THREADED TOOL NOSE ON THE ACCURACY OF THE MACHINED THREADED SURFACE

In order to develop an experimental research concerning the influence exerted by the tool nose position, an adequate device was designed and materialized [7].

Practically, the device ensures the continuous change of the threading tool position between certain limits, to facilitate the simulation of distinct errors of positioning the threaded tool nose relative to the horizontal plane of the workpiece rotation axis.

The device includes a main body by which it could be positioned and clamped in the lathe tool holder; with this aim in view, a parallelipipedic metallic part was attached to the main body of the device.

Along a vertical direction parallel to the axis Oy, a slide could be moved by rotating a screw intended to materialize a possibility of positioning of the lathe tool nose over or under the horizontal plane of the workpiece rotation.

In the slide, there is a bolt intended to support and position a disk that could be rotated around an axis parallel to the Oz axis.

After the clamping of the disk in the desired angular position, the disk is immobilized on the slide by means of four screws whose shanks are placed in two arc of circle

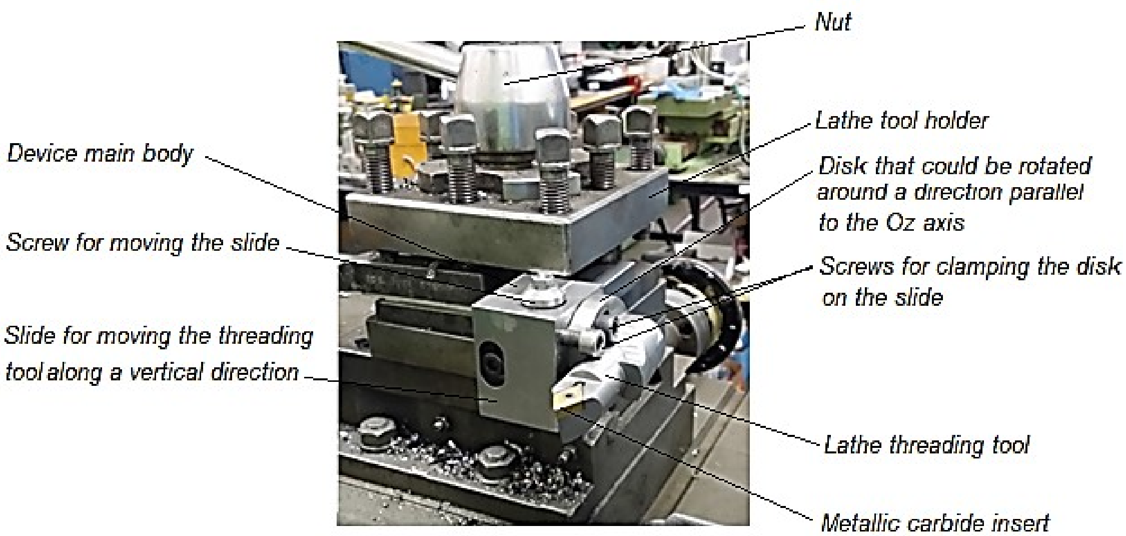

Fig. 6. Device for the experimental investigation of the threaded surface errors generated by the errors of positioning the threading tool nose relative to the horizontal plane of the workpiece rotation axis.

shaped grooves that exist in the disk.

The disk includes also a parallelipipedic zone in which there is a conical hole.

The lathe tool body has also an external conical zone by means of which the threading tool body could be placed and immobilized in the conical hole from the parallelipipedic zone of the disk. In this way, the threading tool body could be rotated around an axis parallel to the *Ox* axis and clamped in the desired position.

A nut placed at the end of the conical surface of the lathe threading tool allows clamping of the tool in the conical hole that exists in the parallelipipedic zone of the disk type part.

A metallic carbide insert that presents an adequate shape to be used in the threading process is mechanically assembled to the lathe threading tool.

To rotate the lathe threading tool around the third rotation axis of the system of coordinates attached to the threading tool nose, the tool holder could be used; it is known that nowadays, the tool holder of the universal lathe has the possibility to be rotated around an axis parallel to the *Oy* vertical axis and immobilized in the desired position by means of a nut placed on the lathe tool post screw; usually, the nut presents a handle to be acted by hand, when it is necessary.

5. CONCLUSIONS

The threaded surfaces are used especially in materializing the detachable joints; such surfaces could be obtained by machining on a lathe.

One of the factors able to exert influence on the accuracy of the surfaces obtained by distinct machining methods is the relative position of the cutting tool nose relative to the workpiece surface.

In the case of the threading process developed on a lathe, from the point of view of the machining accuracy, there is the possibility of wrong positioning of the threading tool along an axis parallel to the vertical axis of a coordinate axes system attached to the technological system.

The position of the threading tool nose along the above mentioned axis exerts influence on the value of the minor diameter of the threaded surface. A theoretical relation was determined to show how the distance between the threading tool nose and the horizontal plane of the workpiece rotation axis affects the value of the minor diameter.

To experimentally test the validity of the theoretical model, a device able to ensure the change of the threading tool position was designed and achieved. The device allows the moving and clamping of the tool nose along the vertical axis of the coordinate axes system, by moving a slide along a guide that exists in the device main body. The results of the preliminary experimental tests proved the possibilities of using the device within an extended experimental research and the validity of the theoretical considerations finalized by a mathematical model. Since the device ensures also other possibilities of changing the position of the threading tool by its moving along and rotating around other axes of the coordinates axes system, in the future there is the intention to develop a more systematic research concerning the influence of the errors of positioning the threading tool nose on the values of the parameters that characterize the threaded surface performed on a lathe.

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