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SELECTION OF A METHOD FOR MACHINING AN ARCHIMEDEAN SPIRAL GROOVE

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Abstract: *The problem of machining a spiral groove in a metal workpiece was raised to achieve a device for evaluating the thermal expansion capacity of plastics. It was found that a groove in the form of an Archimedean spiral corresponds to the requirements derived from the operation of a device conceived for developing scientific research. Five alternatives for the machining of the groove have been identified, and the imposed decision method was used to select the most convenient machining alternative. The use of this method involved a comparison of the alternatives two by two and based on previously established criteria to select the alternative of machining the groove in the form of an Archimedean spiral. It was found that for the conditions considered, the most convenient alternative is machining on a milling machine equipped with a numerical control subsystem.*

Key words: *spiral groove, Archimedean spiral, machining alternatives, imposed decision method, turning, milling, CNC machine tool.*

1. INTRODUCTION

In machine manufacturing, there can sometimes be situations where the parts to be made have grooves with a certain cross-section and are arranged along a spiral. Such grooves can be classified by taking into account the surface on which they are located (on cylindrical, flat, conical surfaces, etc.), the shape of the profile in a cross-section (having the shape of a square, a rectangle, the shape of the letter V, the so-called shape dovetail, the shape of a semicircle, etc.), by the type of spiral along which the channel is arranged, by the dimensions that characterize the cross-section and the length of the spiral, etc.

There are different uses of such grooves located on the surfaces of parts in machine building. Well-known are the spiral grooves located on cylindrical or conical surfaces and which constitute the threads.

In the case of spiral grooves found on flat surfaces, one of the most well-known such grooves is the one located on a disc type part and which determines the movement of the universal chuck jaws frequently used on lathes or other categories of universal machine tools.

Other grooves made on the flat surfaces of some parts are used in fluid mechanics [1]. Interesting use of flat spiral grooves is the one found in so-called spiral thrust bearings, in which the grooves contribute to reducing the intensity of friction processes between surfaces [2-6].

Archimedean or other types of spirals are also preferred in the case of tools used for precise and high-productivity machining conical gears with curved teeth, such as Fiat Mammano teeth Oerlikon-Spiromatic teeth [7, 8].

In metal parts, spiral grooves placed on flat surfaces can essentially be obtained by turning or milling processes. Aspects related to the machining of flat spiral channels by different processes have been subjected to analysis and evaluation by researchers interested in such a problem [9-12].

In the research whose results were presented in this paper, the need to perform flat spiral grooves to be used to evaluate the expansion of some plastic spirals was considered. It has thus

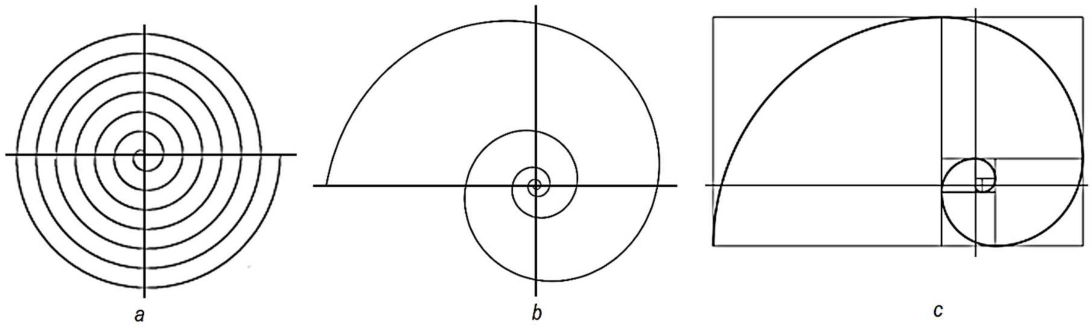

Fig. 1. Types of flat spiral curves: *a* – Archimedean spiral; *b* – logarithmic spiral; *c* – golden spiral.

been found that flat spiral grooves can be made by milling or turning processes. The results of an analysis developed to select a process for making flat spiral grooves in workpieces made of metal materials are presented in this paper.

2. ARCHIMEDIAN SPIRAL

Mathematically, a flat spiral is a curve generated by the movement of a point around a fixed point and from which the moving point moves continuously. Several types of flat spirals (fig. 1) correspond to distinct ways of generating and defining mathematical functions (Archimedean spiral, logarithmic spiral, golden spiral, etc.).

In the situation addressed in this paper, it was considered that type of spiral corresponds to the spiral with the longest length for an area of predetermined dimensions.

Such a requirement is met by the so-called Archimedean spiral, defined by the mathematical relation:

$$\rho = f(\theta), \qquad (1)$$

where ρ is the distance from the fixed point (origin of the coordinate plane system) to the moving point, as defined above, and θ is the angle formed by the linear segment joining the fixed point with the moving point to the positive half-axis of the abscissa ($\theta > 0$).

The Archimedean spiral can also be defined by using the Cartesian coordinates of the moving point:

$$\begin{cases} x = \rho \cdot \cos\theta \\ y = \rho \cdot \sin\theta, \end{cases} \qquad (2)$$

where $\theta \in [\,0;\ 2\pi k],\ k \in \mathbb{N}$.

From a technological point of view, the Archimedean spiral has the advantage of a relatively simple possibility of materialization by using a rotational movement and a translational movement with constant speeds. Such movements can be easily performed on

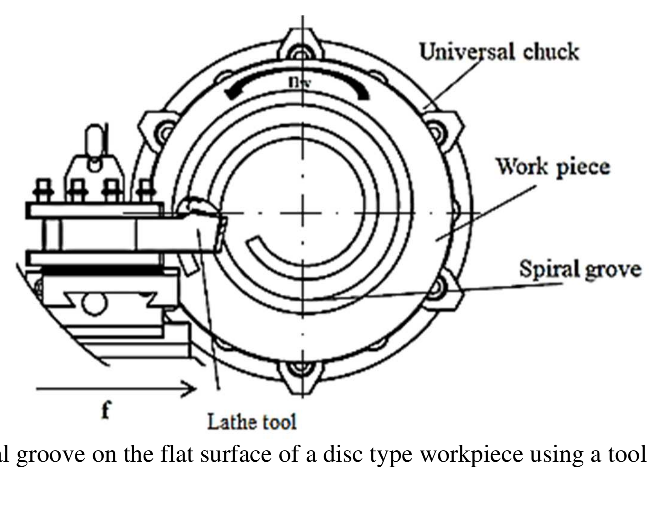

Fig. 2. Machining a spiral groove on the flat surface of a disc type workpiece using a tool lathe on a universal lathe.

some universal machine tools, such as lathes or milling machines.

3. TECHNOLOGIES APPLICABLE FOR GENERATING GROOVES IN THE FORM OF AN ARCHIMEDEAN SPIRAL

We will consider the need to make a spiral channel on the flat surface of a disk-type workpiece. A part with such a groove is to be included in a device used for evaluating the thermal expansion capacity of polymeric materials in the composition of parts manufactured by 3D printing.

The most accessible alternative for making such a groove is the one applicable on universal lathes (fig. 2). A tool lathe with the active part designed to generate the desired channel in the workpiece gradually could be located and clamped in the universal chuck of the lathe. The lathe apron and the lathe tool will ensure initial penetration along a longitudinal direction and subsequently make a transverse feed movement, with repeated penetrations of the tool tip, until the complete channel is completed.

The lathe could also be used for milling the spiral channel. In this case, a device could be clamped in the tool holder of the universal lathe which will incorporate, in principle, an electric motor having a mandrel mounted on the motor shaft, a finger milling tool located and clamped in the mandrel, and a parallelepiped-shaped part secured to the electric motor housing and which will allow the device to be attached to the tool holder of the universal lathe (fig. 3).

In the case of lathes equipped with numerical control subsystems, the lathe tool (or possibly a finger milling tool which can be rotated at a peripheral speed corresponding to the cutting speed when milling) could be mounted in a revolver head (fig. 4) or a tool holder. Movements according to predetermined trajectories and adequate feed rates will ensure conditions for the gradual generation of a helical groove on the flat surface of the disc type part.

On vertical milling machines, devices can be used that ensure a slow rotation of the workpiece employing a cylindrical gear that receives a rotational movement from the screw used to make a feed movement by the machine tool table (fig. 5). In this case, the flat disc workpiece performs both the rotational movement and a

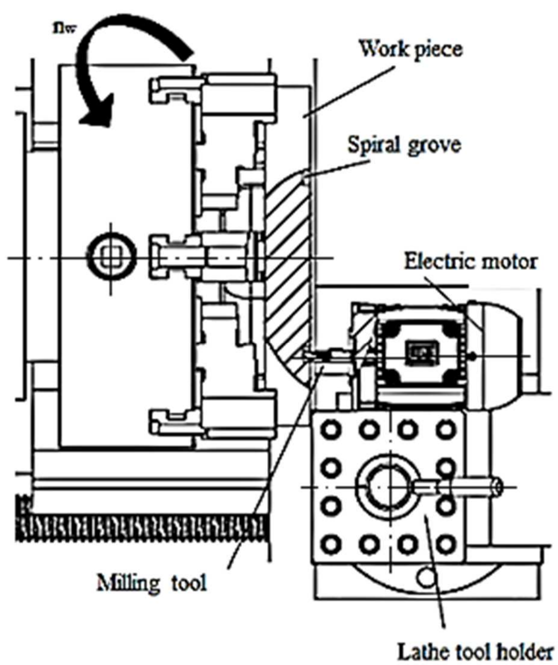

Fig. 3. Machining a spiral groove on the flat surface of a disc-type workpiece using a device with a finger milling tool on a universal lathe.

rectilinear feed movement necessary for machining the spiral groove. The finger milling tool only performs the rotational movement necessary to develop a cutting process after an initial penetration along a vertical direction to ensure the predetermined depth of cut.

4. SELECTION OF A TECHNOLOGY FOR THE GENERATION BY MACHINING OF AN ARCHIMEDEAN SPIRAL GROOVE

The need to machine a square profile groove measuring 2.3 mm x 2.3 mm, in an aluminum alloy plate measuring 15 mm x 15 mm was taken into account.

Based on the above brief analysis, it can be appreciated that the following machining processes allow the groove to be obtained:

a) Turning on the universal lathe;

b) Milling on the universal lathe;

c) Turning on a CNC (computer numerical control) lathe;

d) Milling on a vertical milling machine using a workpiece rotating device coordinated with the longitudinal feed movement;

e) Milling on a CNC milling machine.

The selection of one of these processes can be done by using one of the methods usable in this regard. To identify a solution from several available alternatives, when the decision to be determined is characterized by individual applicability and under conditions of certainty, one of the following methods could be used, for example [13]: pairwise comparison matrix method, the method of the imposed decision, global utility method, analytic hierarchy process (AHP), analytic network process (ANP), technique for order the preference by similarity to ideal solution (TOPSIS), weighted sum model (WSM), weighted product model (WPM), multi-attribute utility theory (MAUT), superiority and inferiority ranking method (SIR method), potentially all pairwise rankings of all alternatives (PAPRIKA), value analysis (VA), axiomatic design method, etc.

In "Gheorghe Asachi" Technical University of Iași, Professor Vitalie Belous recommended and used a method based on the weighting of selection criteria and available solution alternatives; the method is also known as the "imposed decision technique" [14].

In the following, the possibility of using this method to select the process of machining a

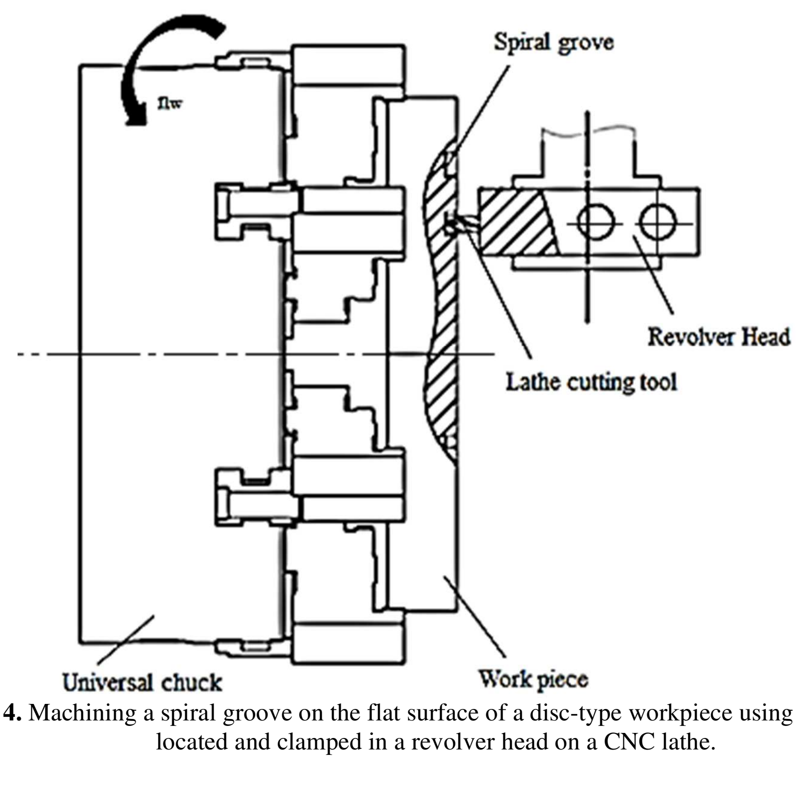

Fig. 4. Machining a spiral groove on the flat surface of a disc-type workpiece using a lathe tool located and clamped in a revolver head on a CNC lathe.

into

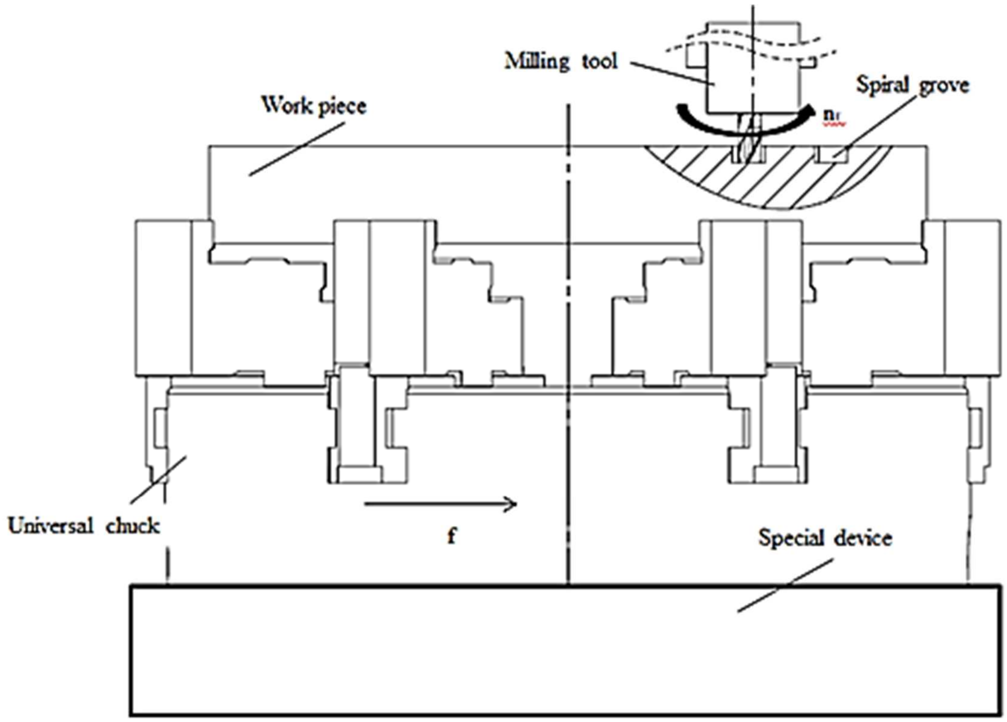

Fig. 5. Machining a spiral groove on the flat surface of a disc-type workpiece using a device with a finger milling tool on a vertical milling machine.

groove with a square section and having the shape of an Archimedean spiral was considered.

A first step in applying this method of imposed decision requires identifying the criteria by which the selection will be made.

We will consider that the following criteria could be used to choose one of the 5 processes listed above for spiral groove machining:

A) Machining productivity;

B) The cost of machining equipment;

C) Accuracy of spiral groove machining;

D) Ease of access to the equipment.

The next stage of applying the imposed decision method aims at weighting the evaluation criteria by successively comparing each of the criteria with the other criteria taken into account. This comparison can be made using the information in Table 1.

Comparing the criteria two by two can lead to results of type 1-0 when the first criterion is more important than the second, 0-1 when the second criterion is considered more important, and respectively 0.5-0.5 when the two compared criteria are considered to be of equal importance.

The number of N_c comparisons required to be made corresponds to the relation:

$$N_c = \frac{n(n-1)}{2}, \qquad (3)$$

where *n* is the number of criteria compared.

In the penultimate column of Table 1 was entered the sum of the marks awarded to each of the criteria. In the last column, a coefficient of

Table 1

Weighting of the evaluation criteria of the available alternatives for machining a spiral groove.

Cri□erion *j*	**Comparison no.**						**Sum N_{dj}**	**Coefficien□of impor□ance K_j**
	1	2	3	4	5	6		
A (Machining productivity)	0	0.5	0				0.5	0.083
B (The co□t of machining equipment)	1			0.5	0		1.5	0.25
C (Accuracy of □piral groove machining)		0.5		0.5		0	1.0	0.16
D (Ea□e of acce□□ to the equipment)			1		1	1	3.0	0.5

Table 2

Comparison of available alternatives for spiral groove machining using each of the selection criteria considered.

Alternative	Comparison no.										Sum N_i	Coefficient of importance
***A* (Machining productivity)**												
	1	2	3	4	5	6	7	8	9	10	N_i	K_{i1}
a	0	0	0.5	0							0.5	0.05
b	1				1	0.5	0				2.5	0.25
c		1			0			1	0		2.0	0.20
d			0.5			0.5		0		0	1.0	0.10
e				1			1		1	1	4	0.40
***B* (The cost of machining equipment)**												
	1	2	3	4	5	6	7	8	9	10	N_i	K_{i2}
a	1	1	1	1							4	0.40
b	0				1	0.5	1				2.5	0.25
c		0			0			0	0.5		0.5	0.05
d			0			0.5		1		1	2.5	0.25
e				0			0		0.5	0	0.5	0.05
***C* (Accuracy of spiral groove machining)**												
	1	2	3	4	5	6	7	8	9	10	N_i	K_{i3}
a	0.5	0	0.5	0							1	0.10
b	0.5				0	0.5	0				1	0.10
c		1			1			1	0.5		3.5	0.35
d			0.5			0.5		0		0	1	0.10
e				1			1		0.5	1	3.5	0.35
***D* (Ease of access to the equipment)**												
	1	2	3	4	5	6	7	8	9	10	N_i	K_{i4}
a	1	0.5	1	0							2.5	0.25
b	0				0	0.5	0				0.5	0.05
c		0.5			1			1	0.5		3.0	0.30
d			0			0.5		0		0	0.5	0.05
e				1			1		0.5	1	3.5	0.35

importance K_j was entered, determined as a ratio between the sum of marks awarded to each of the criteria and the number of comparisons made.

In the next step, we compare each of the alternatives to solve the problem addressed by using the previously weighted criteria.

The way of working is similar to the one used to weight the criteria, namely the criteria are compared two by two, and the results (possible in one of the forms 1-0, 0-1, and 0.5-0.5) were listed in Table 2.

In a final step, the importance coefficients N_{vi} of each of the alternatives i considered are calculated by summing the products of the importance coefficients K_j of each criterion with the importance coefficient of each alternative K_{ij} obtained using that criterion j:

$$N_{vi} = \sum_{j=1}^{N} K_{ij} K_j \quad (4)$$

where K_{ij} are the values of the importance coefficients associated with variants *a*, *b, c, d* and *e*, for each of the criteria *A*, *B*, *C* and *D*, and K_j are the values of the importance coefficients corresponding to each of the evaluation criteria *j*.

In the case of spiral grooves machining processes, it will be possible to write:

$$N_{va}=0.05\cdot 0.083+0.4\cdot 0.25+0.1\cdot 0.16+0.25\cdot 0.5=0.245 \quad (5)$$

$$N_{vb}=0.25\cdot 0.083+0.25\cdot 0.25+0.1\cdot 0.16+0.05\cdot 0.5=0.124 \quad (6)$$

$$N_{vc}=0.2\cdot 0.083+0.05\cdot 0.25+0.35\cdot 0.16+0.3\cdot 0.5=0.235 \quad (7)$$

$$N_{vd}=0.1\cdot 0.083+0.05\cdot 0.25+0.1\cdot 0.16+0.05\cdot 0.5=0.112 \quad (8)$$

$$N_{ve}=0.4\cdot 0.083+0.05\cdot 0.25+0.35\cdot 0.16+$$

$$+0.35\cdot 0.5=0.277 \quad (9)$$

The analysis of the values of the importance coefficients N_{vi} corresponding to each of the alternatives i for machining the spiral groove highlights that the alternative *e* is the most convenient, as it corresponds to the highest value of the importance coefficient. The order of evaluation of the alternatives is, in this case, *e-c-a-b-d*. It corresponds to the order of the values of the importance coefficients determined by the relations (5), (6), (7), (8), and (9).

5. CONCLUSIONS

From the literature study, it is found that there are distinct flat spirals, which can be defined by appropriate mathematical relationships. It was found that the Archimedean spiral ensures the fulfillment of specific conditions to achieve a spiral groove usable for evaluating the thermal expansion capacity of plastics. Five alternatives for machining an Archimedean spiral groove have been identified. The selection of one of these alternatives was made possible by the use of selection criteria. By applying the method of the imposed decision, it was concluded that the optimal method of machining the groove in the form of an Archimedean spiral is milling on a numerically controlled milling machine. In the future, other methods of machining the groove in the form of an Archimedean spiral will be identified, and other methods of selecting an alternative from the available alternatives will be used.

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Selectarea unei metode de prelucrare a unui canal sub forma unei spirale arhimedice

Abstract. Problema prelucrării unei caneluri spiralate într-un semifabricat metalic a fost abordată în vederea realizării unui dispozitiv de evaluare a capacității de dilatare termică a materialelor plastice. S-a constatat că un canal sub forma unei spirale arhimedice corespunde cerințelor derivate din funcționarea unui dispozitiv conceput pentru dezvoltarea unei cercetări științifice. Au fost identificate cinci alternative pentru prelucrarea canelului, iar metoda deciziei impuse a fost utilizată pentru a selecta cea mai convenabilă alternativă de prelucrare. Utilizarea acestei metode a presupus o comparare a alternativelor două câte două, pe baza unor criterii stabilite anterior, pentru a selecta alternativa de prelucrare a canalului sub forma unei spirale arhimedice. S-a constatat că pentru condițiile luate în considerare, cea mai convenabilă alternativă este prelucrarea pe o mașină de frezat echipată cu un subsistem de comandă numerică.

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