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Kinematic Structures for Surface Processing with Straight-Line Directrix and Circle Generatrix

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Abstract
The technical surfaces are characterized by directrix (D) and generatrix (G). They can be materialized, obtained by copying, obtained as the trajectory of a point, obtained as a wrapper of a family of curves, obtained by rolling or programmed. It turns out that 36 ways to generate an area by combining the ways of obtaining the directrix and the generatrix are possible. This paper exemplifies the six ways to obtain an area characterized by a straight directrix obtained by copying.

Keywords
directrix, generatrix, surface, links

1. Introduction

A part is bounded by one or more unitary surfaces [1, 3], each being described by a certain directrix curve and a certain generatrix curve. Each surface, simpler or more complex, can be obtained by several ways. The machining process adopted has a direct influence on the dimensional accuracy and surface quality thus generated.

The directrix and generatrix of a part can be [3]:

- materialized (M, m);
- obtained kinematically:
  - by copying (Co, co);
  - as a trajectory of a point (Ci_{tp}, ci_{tp});
  - as a wrapper of a family of curves (Ci_{fc}, ci_{fc});
  - by rolling (R, r);
  - programmed (P, p).

The mentioned ways of making the directrix and the generatrix allow to obtain 36 combinations for generating a surface. These are shown in Table 1.

Table 1. Possible combinations of generating a surface, depending on the nature of the director and generator [3]

		Directrix					
		M	Co	Ci_{tp}	Ci_{fc}	R	P
Generatrix	m	M&m	Co&m	Ci_{tp}&m	Ci_{fc}&m	R&m	P&m
	co	M&co	Co&co	Ci_{tp}&co	Ci_{fc}&co	R&co	P&co
	ci_{tp}	M&ci_{tp}	Co&ci_{tp}	Ci_{tp}&ci_{tp}	Ci_{fc}&ci_{tp}	R&ci_{tp}	P&ci_{tp}
	ci_{fc}	M&ci_{fc}	Co&ci_{fc}	Ci_{tp}&ci_{fc}	Ci_{fc}&ci_{fc}	R&ci_{fc}	P&ci_{fc}
	r	M&r	Co&r	Ci_{tp}&r	Ci_{fc}&r	R&r	P&r
	p	M&p	Co&p	Ci_{tp}&p	Ci_{fc}&p	R&p	P&p

In technics, the surfaces are obtained by machining on machine tools, by relative movements between the tool and the workpiece. The directrix is obtained as a result of one or more movements, one being the main movement and the other - if any - advance movements. The generatrix is obtained as a result of one or more advancing movements. If the generatrix is materialized by the tool profile, the presence of an advance movement is not required to obtain it. One or more auxiliary movements are usually required for the entire machining to run properly.

The various machining processes are performed:
- by removing material;
- by redistribution of material;
- by adding material.

There are machine tools that can make parts in all three ways.

2. Machining with Straight Directrix Obtained by Copying and Materialized Circle Directrix (case Co&m)

Any copy machining scheme requires the existence of a follower and a template. The appropriate case is exemplified in Figure 1 by a scheme of machining by EDM with massive electrode, the straight directrix of the generated surface is being obtained by copying after the pattern.

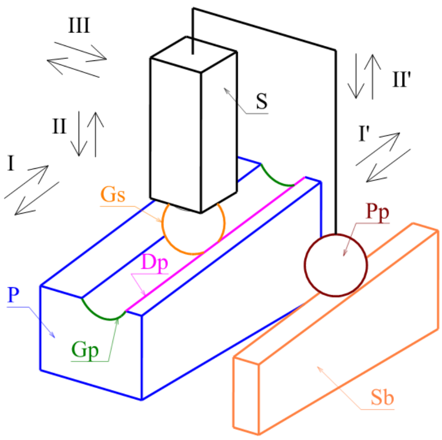

Fig. 1. Machining scheme corresponding to the case Co&m

In order to obtain the directrix (Dp) of the surface of the part P, two movements are needed, I and II, perpendicular to each other, simultaneous and identical (or proportional). Movement I is the main one and is performed along the workpiece (P). Movement II is an advance movement and is performed as a result of copying the pattern profile (Sb). Copying is done with a mobile, translatable follower (Pp) that performs movement II'. If the part and the pattern are fixed, then the follower also performs movement I', identical to movement I. If the part and pattern are mobile, the pattern performs movement I' identical to movement I, and the follower performs only movement II'.

The surface generatrix (Gp) is materialized on the tool profile (S), which is a profiled electrode.

The generatrix is materialized, and therefore no advance feed movement is required [3].

Movements I and II can also act as positioning movements, performed not during the machining process. An auxiliary positioning movement III is also required, which can be done manually.

A kinematic scheme of principle, with kinematic chains-type [3] which ensures that the movements specified in Figure 1, are shown in Figure 2.

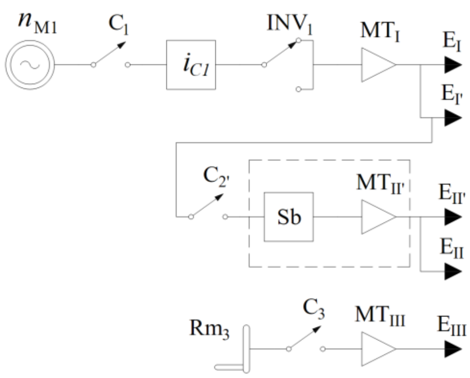

Fig. 2. Kinematic diagram of principle, corresponding to the case Co&m

The main kinematic chain has in structure a motor M_1, with speed n_{M1}, a coupling C_1, a mechanism with constant transfer ratio i_{C1}, demultiplier, a direction reversing mechanism INV_1, a transformation mechanism MT_I from rotational motion to translational motion and the executing element E_I, which drives the tool S in movement I. The executing element $E_{I'}$ is in solidarity with E_I and performs identical movements.

The kinematic chain of the advancing motion II, executed by the follower Pp, takes over the motion I' and through the transformation mechanism $MT_{II'}$, a pattern-follower type (actually a cam and follower mechanism), transmits it to the follower Pp. The presence of a $C_{2'}$ coupling is useful. The motion II' of the follower is transmitted as movement II of the tool S, the two movements being identical.

A minimalist kinematic chain with manual drive from an R_{m3} hand wheel is provided for auxiliary movement III. The MT_{III} transformation mechanism, possibly a screw-nut type, transforms the rotational movement of the hand wheel into a translational movement of the E_{III} executing element. C_3 coupling is optional.

The case Co&m can also be exemplified by a copying machining scheme with a profiled ball milling cutter, Figure 3.

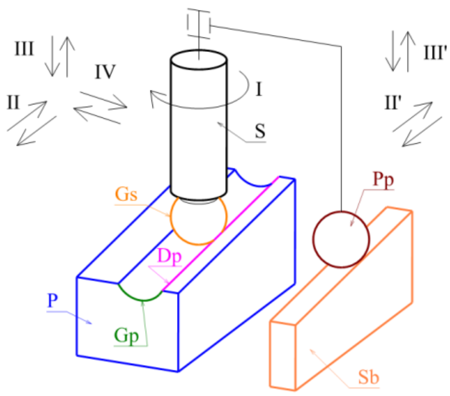

Fig. 3. Milling machining scheme corresponding to the case Co&m

The main rotational movement I, performed by tool S, is imperative. The other movements are identical to those shown in Figure 1, with the observation that movement II (movement I in Figure 1) becomes an advance movement. Please note that movements II, III and IV are not dependent on the main movement I.

The kinematic structure of principle, corresponding to the diagram in Figure 3, is shown in Figure 4. It contains in addition to the kinematic diagram in Figure 2 the main kinematic chain, composed of the motor M_1, the coupling C_1, the mechanism with variable transfer ratio i_{v1} for adjusting the tool speed, a mechanism with constant transfer ratio i_{C1} and the executing element E_I. Since the output motion is of the same nature as the input motion, the presence of a transformation mechanism is not required.

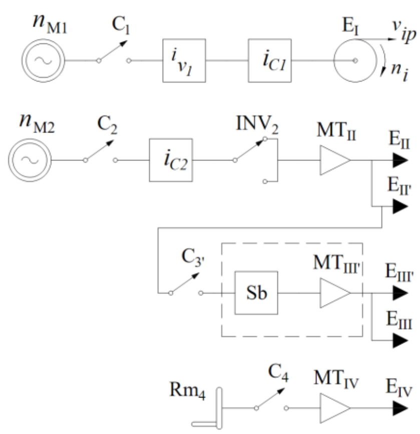

Fig. 4. Kinematic diagram of principle, corresponding to the machining scheme from Figure 1

3. Machining with Straight Directrix and Circle Generatrix, both obtained by copying (case Co&co)

Generating surfaces by copying the directrix and the generatrix can be done by milling with a tool suitable for the type of surface, which is copied according to the pattern. In the processing diagram in Figure 5 it can see how to copy the surface of the pattern using the translatable follower. Movement I is the main rotational movement driven by an electric motor. Movements II and III are alternative translational movements with the role of generating advance movements and can be activated depending on the position of couplings $C_{2'}$ and $C_{3'}$ (Figure 6 - kinematic diagram of principle) and will always have the same position as movements II' and III between the pattern and the follower. In this case, these two movements are continuous and identical. Movement IV, executed in a horizontal direction and perpendicular to movements II and III, has a role in obtaining the circle generatrix. It is not a continuous movement, it makes a movement, of a certain value, after each end of the movement II.

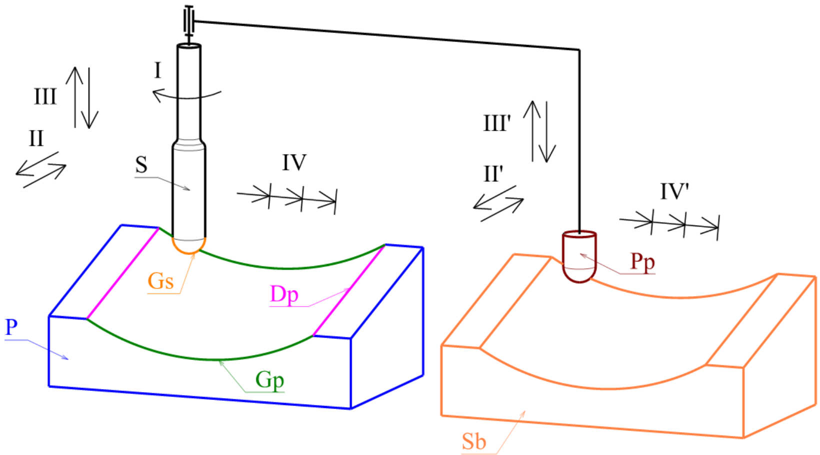

Fig. 5. Milling machining scheme corresponding to the case Co&co

The kinematic diagram of principle in Figure 6 shows a possible way to make the connections of the kinematic chains necessary for the processing scheme presented in Figure 5. The kinematic chain of the main movement I is driven by its own electric motor M_1, and the kinematic chains of the movements II, III and IV are driven by a second M_2 electric motor.

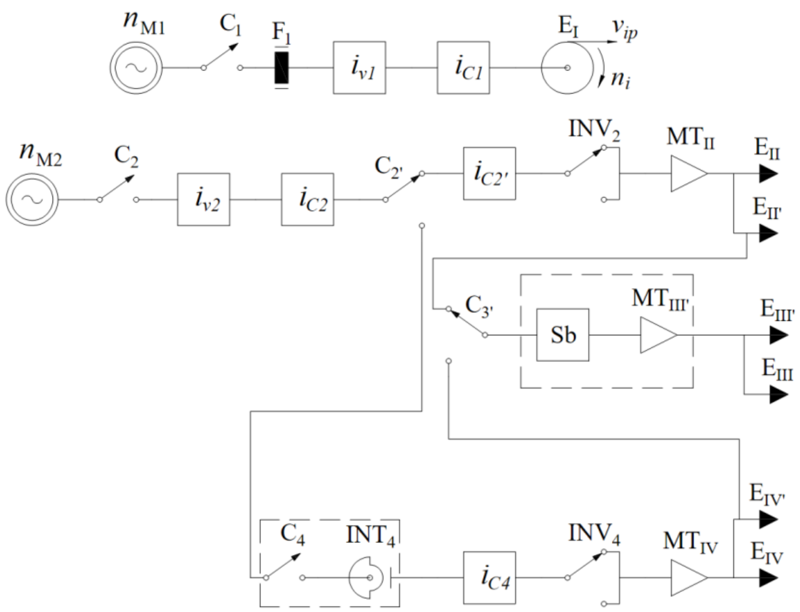

Fig. 6. Kinematic diagram of principle, corresponding to the case Co&co

4. Machining with Straight Directrix Obtained by Copying and Circle Generatrix Obtained Kinematically as a Trajectory of a Point (case Co&ci$_{tp}$)

A suitable example is the process of turning by machining of a spherical surface copied after a cylindrical pattern having one (or more) flat areas, Figure 7. The main rotational movement I executed by workpiece P is imperative. It needs to combine several movements to obtain the desired final surface. This scheme needs to have four sleighs to be able to obtain the surfaces. The first sledge is able to perform a movement closer and further away from the axis of rotation of the part – the auxiliary movement V which ensures the radius of the spherical surface of the machined part. With this sledge the tool is assembled directly. Under the first sledge is a second one that performs a rotational movement III, alternative, necessary to obtain kinematically the circle generatrix. The third sleigh is intended to perform the movement II, of faithful copying of the movement II' made by the fallower Pp permanently in contact with the pattern Sb (a cam). The third sleigh moves and the other two sleighs are on top of it. Movements II and II’ are used for copying the straight directrix from the pattern to the workpiece. The last sleigh is used to perform the auxiliary movement IV, of axial positioning of the center of the spherical surface of the part.

The kinematic diagram of principle from Figure 8 reflects a possibility of making the connections between the kinematic chain. The kinematic chain of movement I is driven by a separate electric motor which drives in rotational motion both the semi-finished product and the pattern. After each movement III, to the left or to the right, there is a movement V (discrete radial advance) to bring a new cutting layer and finally obtain the desired radius of the spherical surface of the part. Movement III can also be performed manually using the R_{m3} handwheel. For manual movements IV and V only manual drives are provided in a minimalist way, using R_{m4} and R_{m5} handwheels.

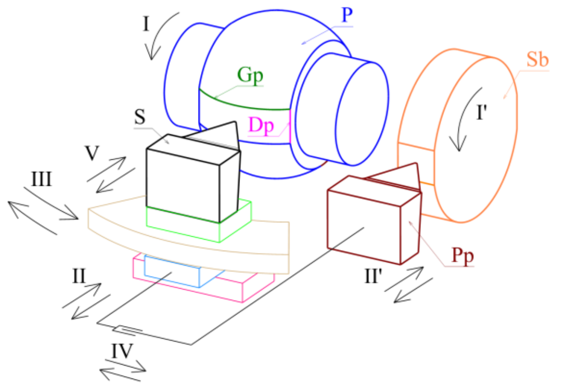

Fig. 7. Turning scheme corresponding to the case Co&ci$_{tp}$

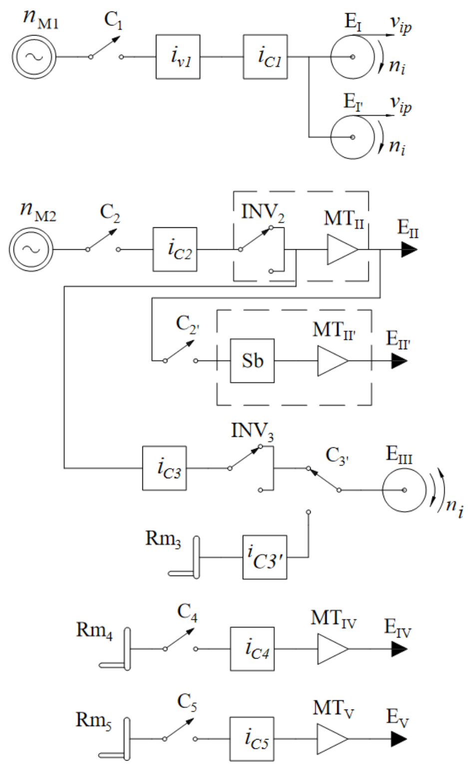

Fig. 8. Kinematic diagram of principle, appropriate to the case Co&ci$_{tp}$

5. Generation with Straight Directrix Obtained by Copying and Circle Generatrix Obtained Kinematically as the Envelope of a Family of Curves (case Co&ci$_{fc}$)

The Co&ci$_{fc}$ case is exemplified by the machining scheme in Figure 9, a milling with a disc-shaped profiled tool.

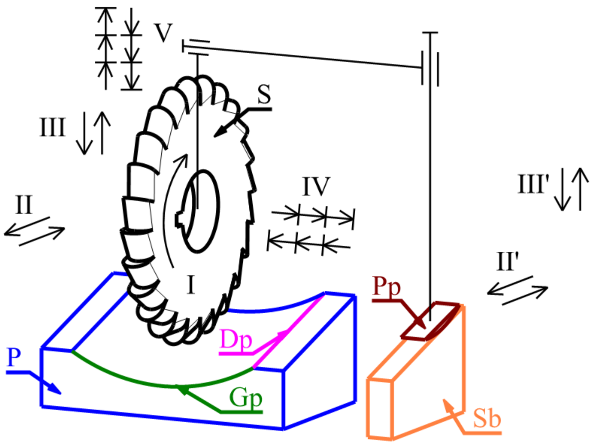

Fig. 9. Milling machining scheme corresponding to the case Co&ci$_{fc}$

The main movement I is imperative and is performed by the cutting tool S. The movements II' and III' contribute to obtaining the directrix and are transmitted to the tool in the form of movements II and III. The generatrix is obtained as a result of the intermittent movement IV in a direction perpendicular to the movements II and III and of an intermittent movement V in the vertical direction.

A possible kinematic scheme is shown in Figure 10.

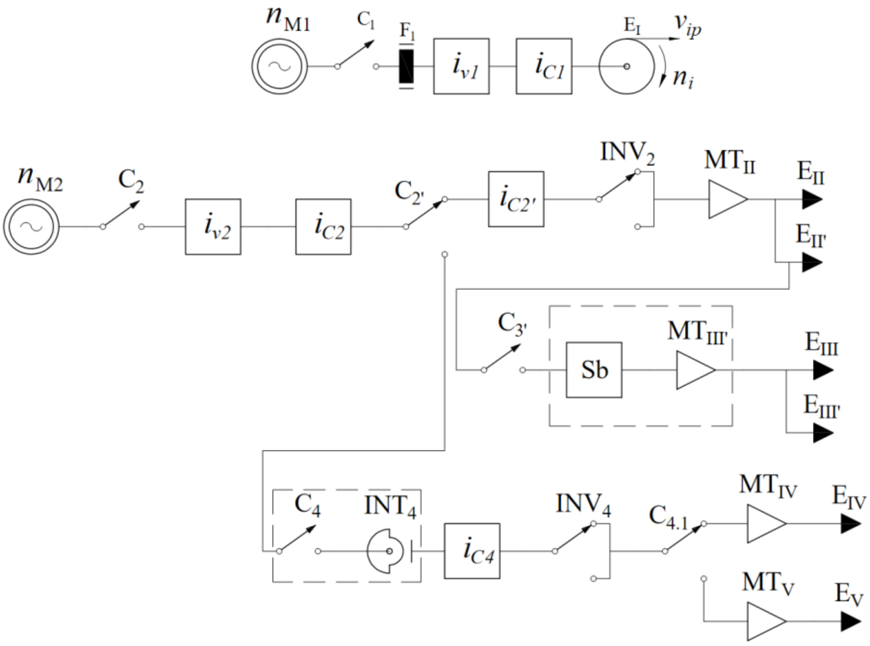

Fig. 10. Kinematic diagram of principle, corresponding to the case Co&ci$_{fc}$

The main kinematic chain is driven in rotational motion by an electric motor M1. Movements II, III, IV, V, II' and III' have the same power source of the same electric motor M2 and are active depending on the appropriate combination of couplings $C_{2'}$ and $C_{4.1}$.

6. Machining with Straight Directrix Obtained by Copying and Circle Generatrix Obtained by Rolling (case Co&r)

The Co&r case can be exemplified by the milling machining scheme, Figure 11. Being a milling operation, the main movement I is performed by the tool. Movements II, of longitudinal feed, and III, of vertical feed are also required to obtain the directrix, the latter being obtained by copying using a cam and fallower mechanism. The follower Pp executes movement II', identical to movement II, and generates movement III', which is transmitted identically to tool S as movement III. The generatrix Gp of the workpiece is obtained by rolling as a result of the combination of movements IV and V, both discrete. Movement IV has a rotational motion which has its center where the imaginary center of the circle from the tool's profile is. Movement V, which is a translational motion, is activated simultaneous with movement IV. This is a must for a rolling to be possible.

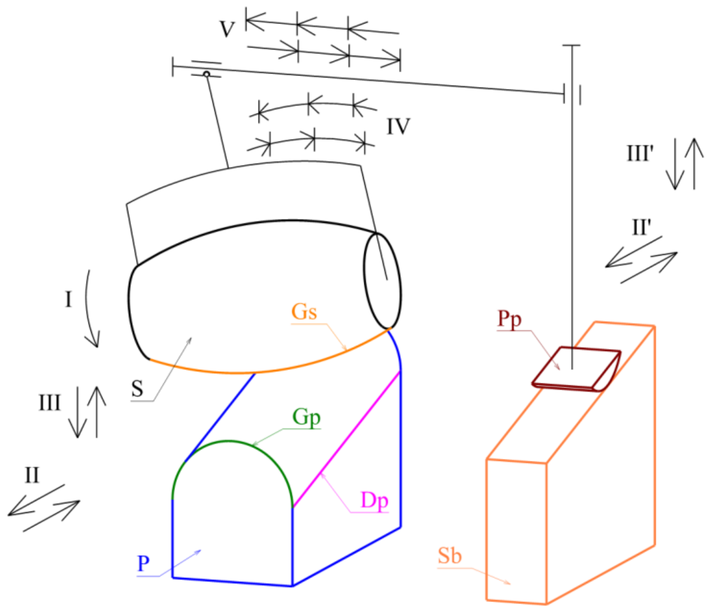

Fig. 11. Milling machining scheme corresponding to the case Co&r

Figure 12 shows a kinematic diagram of principle with links, appropriate to the case. The main rotational movement I is executed by a distinct kinematic chain. The feed movements for obtaining the directrix and the generatrix are driven from the same M_2 electric motor. The positioning of the tool in relation to the part, auxiliary movement, can be done from the same combination of the movements IV and V.

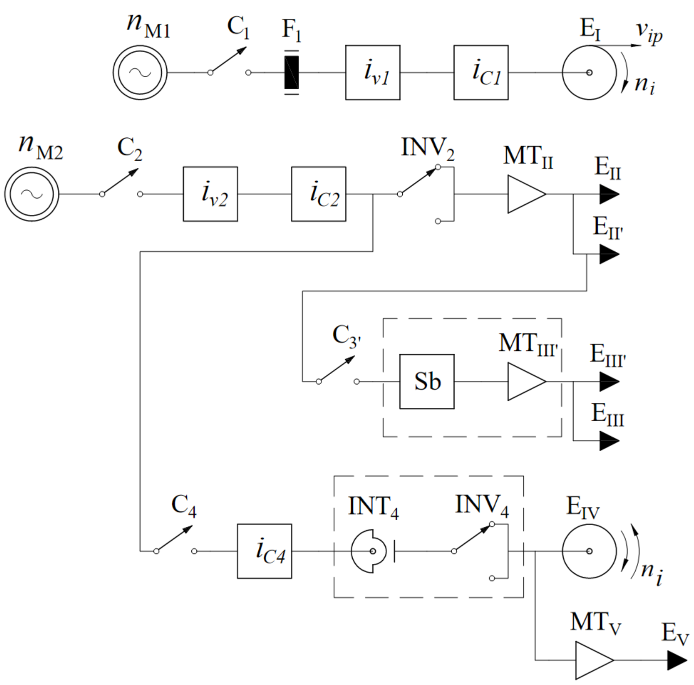

Fig. 12. Kinematic diagram of principle with links, appropriate to the case Co&r

7. Machining with Straight Directrix Obtained by Copying and Programmed Circle Generatrix (case Co&p)

Any processing scheme with circle generatrix obtained by copying can be transformed into a processing scheme with programmed circle generatrix. The pattern is dematerialized and the generatrix is performed by the program run by ECN. The program contains the same information as the physical pattern, but in the form of data. Extrapolating from this case, any machining scheme with immaterialized generatrix obtained kinematically can be transformed into processing scheme with programmed generatrix. An eloquent example is the comparison between Figure 5 and Figure 13. In Figure 5 the generatrix is materialized on the template and is copied on the workpiece by the follower that copies exactly the shape of the pattern. In Figure 13 the pattern has a different shape and exists to copy the directrix on the workpiece by the follower, being necessary only a two-way movement along the directrix of the contact surface. The circle generatrix is obtained as a result of the commands sent by the ECN to the machine tool. In conclusion, the circle generatrix materialized on the pattern in Figure 5 is found in the form of data in Figure 13.

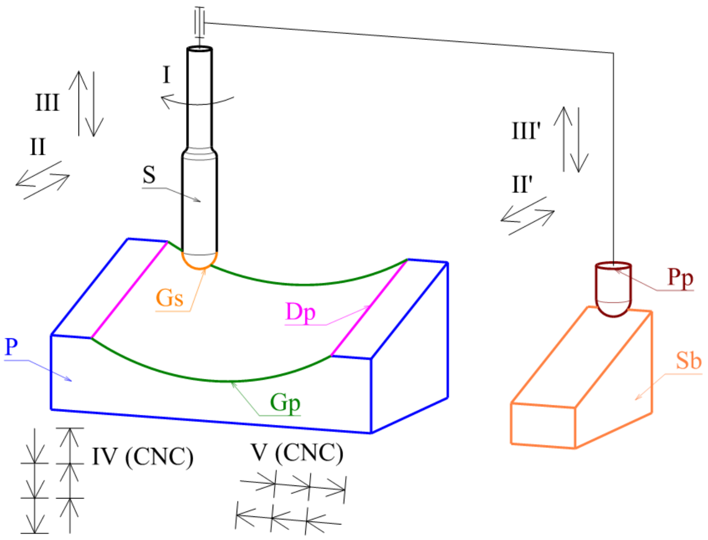

Fig. 13. Milling machining scheme corresponding to the case Co&p

The main rotational movement I is performed by the cutting tool S, driven by an electric motor M_1. The directrix is obtained by sliding the follower on the pattern, in the directions of movements II 'and III' which are transposed to the cutting tool in the form of movements II and III - continuous, variable and alternative movements. Movements IV and V are numerically controlled and contributes to obtaining the generatrix. These two movements are performed independently and discreetly.

Figure 14 is a possible kinematic diagram with links appropriate to the scheme of Figure 13.

8. Conclusions

The same surface can be obtained using different machining processes and, at least in theory, using any combination of the realization of the directrix and generatrix curves. Not every such combination is revealed in the literature, and technically and economically efficient are just a few of them.

In order for a processing method of a surface to be evaluated as efficient or not, that processing method must be known. The present paper is particularly oriented in this respect, to present at least one example of how to process a cylindrical surface characterized by straight directrix obtained by copying and circle generatrix achievable in any of the six known ways.

Each presented case is exemplified by a machining scheme and, using the theory of kinematic chains type, an appropriate principle kinematic diagram is presented also.

The evolution of the technique makes the machining with directrix obtained by copying become more and more rare, the tendency being to replace them with machining with programmed directrix.

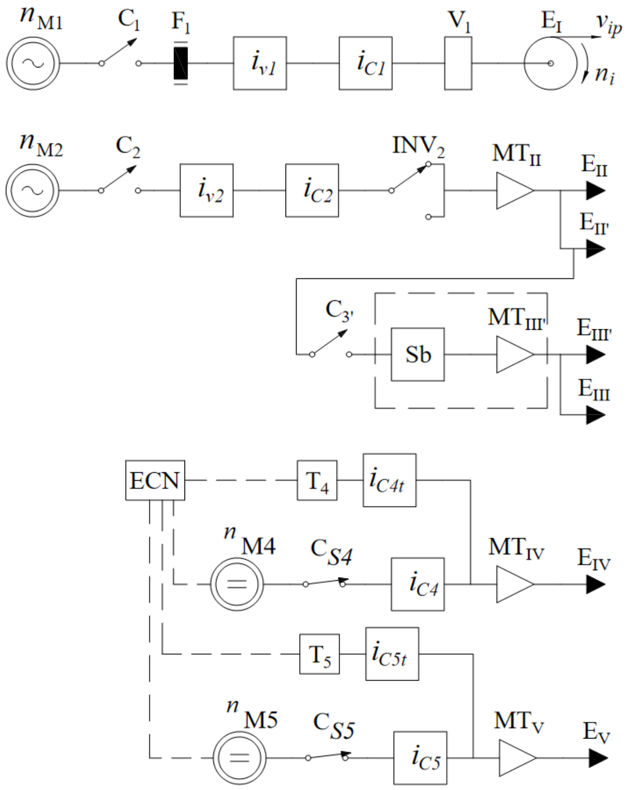

Fig. 14. Kinematic diagram of principle, appropriate to the case Co&p

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