American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-6, Issue-8, pp-103-111
www.ajer.org
Research Paper Open Access

Application of the 5-dof robot for grinding the cutting blade of the curved-tip medical surgical scissor

Phan Bui Khoi[1], Le Van Tham[2], Bui Ngoc Tuyen[1], Do Duc Trung[3]
[1]Hanoi University of Science and Technology, Ha Noi, Viet Nam
[2]Hanoi Technique Technology College, Ha Noi, Viet Nam
[3]Hanoi Industrial University, Ha Noi, Viet Nam
Corresponding Author: Phan Bui Khoi

ABSTRACT: *The article presents the method of application of the 5-dof robot for grinding the blade of the curved-tip medical surgical scissor in case: the scissor is tightly clamped and fixed by the jig; the robot moves with grindstones. Based on the method of blade profile creation and scissor geometrical parameters, we have established a system of blade determination equations. We also determine the triad of the vectors forming a right hand trihedron including: normal axis, tangent axis, binormal axis at each point on the cutting blade and grinding stones. By the method of accompanying trihedron, in order to form the cutting blade, the robot will move so that the trihedron of the cutting blade and the grinding stone coincide. Normally, it's necessary to use the 6-dof to guarantee the above condition. With cylindrical grindstone, the shape of grindstone's blade at the points in the cylinder is identical, the trihedron, characterizing the blade's shape of the grindstone are identical and the cutting position of the stone on the blade can vary flexibly; therefore, the position and orientation of the accompanying trihedron of the stone and the blade is also flexible. This work presents the use of cylindrical grinding wheels with 5-degree robots to grind the blade of the scissors. The computed results on Maple and simulations for visual imagery confirm the reliability of the proposed methodology.*

Keywords: *the curved-tip medical surgical scissor, motion orbit, blade, accompanying trihedron.*

Date of Submission: 02-08-2017 Date of acceptance: 14-08-2017

I. INTRODUCTION

Previous studies [1 - 4] show that the curved-tip medical surgical scissor is a detailed kind of the relatively complicated shape, blade structure and three-dimensional curved blade.

Researches on shaping [5, 6, 7] show that: After extrusion, heat treatment, the blade will be grinded, mainly by hand on two-stone or disk grinders. That's the reason why the blade is curved in an unevenly and unslipperily manner and cutting angle is unstable, varying in a very wide range, even without unclear rules.

During working, the blade is quickly worn, and the two blades aren't in contact at points. Consequently, the scissor is blunt, which causes difficulties for the doctor during surgery, especially when the cuts must be accurate. Therefore, the hospitals in Vietnam often have to use the expensively imported scissors.

Research [6] also proposes a model of blade of the curved-tip medical surgical scissor with even changes, which is convenient for fabrication and use.

The issue is how to choose the method of grinding the cutting blade to make the blade curved and smooth, evenly change, contact and unslip while cutting.

In [8], a 6-dof robot was proposed to grind the blade of the scissors. As such, we need to use seven motors, including the six motors to move the robot's links a seventh motor drives a grinding stone to make a cutting motion of the stone on the blade. The application of the above 6-dof robot is absolutely appropriate, however, in consideration of geometric shape of the grindstone and the contact of the surfaces of grindstone and scissor's blade, a diagram of grinding process with a the 5-dof robot can be established.

In this paper, we present an trajectory design for scissor's blade grinding through the application of the 5-dof robot. Basing on the method of the accompanying trihedron that makes the trajectory design become exact in theoretical aspect. The application of the 5-dof robot brings several advantages, such as the stifness of the robot is enhanced by reducing one driving motor, reducing the load, thus, the processing precision increases. Furthermore, the system structure is simpler, which makes calculation and control faster, etc. On the other hand, the 6-dof robot can be still used, in which, the first five dof are used to make shaping motions and the sixth freedom degree drives the stone motion to form the cutting motion.

By the application of robot into grinding process, the blade is formed with the preset technical specifications: no unwanted cuts by stone, exact cutting angle and blade adequate sharpness to work. Moreover, the use of robots is consistent with the current tendency, which increase the ability to exploit achievements in science and technology, high-techequipment, improve quality and productivity, reduce manufacturing costs. In comparison with the conventional CNC machines, robots are more flexible in processing (more flexible in both structure and programming) [9, 10, 11].

II. MODELING AND SCISSOR'S BLADE EQUATIONS

2.1 Establish the coordinate system

The scissor's coordinate system $O_dX_dY_dZ_d$ are defined as follows, Figure 1:

- The center O_d is the intersection of the plane where the scissor is located and the axis of scissor pin.
- The axis O_dY_d is in the symmetry plane along the scissors, from the center of the pin to the tip of scissor.
- The axis O_dZ_d is the axis of scissor pin.
- The O_dX_d axis is defined in accordance with the right hand rule.

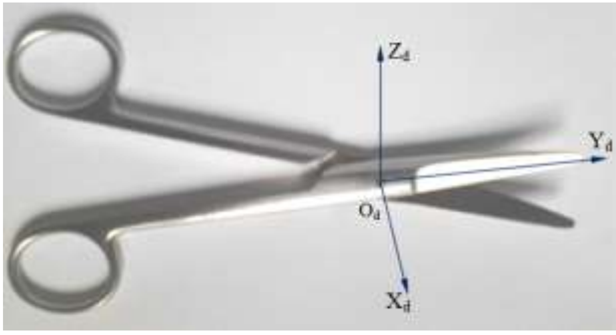

Fig. 1: Coordinate system of the scissor

2.2 Equation of scissor blade's cutting line

The curved-tip medical surgical scissor is acomplicated shape detail, the blade's cutting line structure is three-dimensional curve, and its working by dual working.

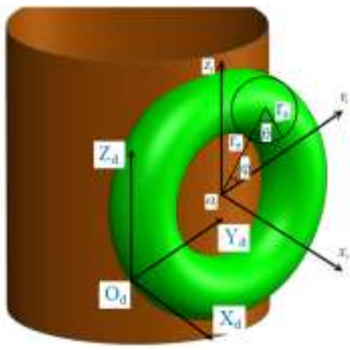

Fig. 2: Geometrical demonstration of the blade

In order to create the curvature of the blade in the $O_dX_dY_d$ plane and the curvature in the $O_dY_dZ_d$ plane and to form the front and the back of the blade, we represent the blade model formed by the intersection of a cylinderical surface and a toroidal surface as shown in Figure 2.

Equation of toroidal surface parameter:

$$\begin{cases} x = x_e + r_s \sin\theta \\ y = y_e + (r_e - r_s \cos\theta)\cos\varphi \\ z = z_e + (r_e - r_s \cos\theta)\sin\varphi \end{cases} \quad (1)$$

In which: r_e is the radius of the circle of the toroidal surface, r_s is the radius of the circle of normal section of the toroidal surface.

$0 \le \varphi \le 2\pi$, $0 \le \theta \le 2\pi$

x_e, y_e, z_e are the coordinates of the center O_1 of the toroidal surface in the coordinate system $O_dX_dY_dZ_d$.
Cyclinder equation:

$$(x - x_c)^2 + (y - y_c)^2 = r_c^2 \qquad (2)$$

x_c, y_c are the coordinates of the center O_2 of cylinderical surface of the coordinate system $O_dX_dY_dZ_d$.

r_c is the radius of the cylinderical surface.

The equation determines the cutting line of the blade:

$$\begin{cases} x = x_e + r_s \sin\theta \\ y = y_e + (r_e - r_s \cos\theta)\cos\varphi \\ z = z_e + (r_e - r_s\cos\theta)\sin\varphi \\ (x - x_c)^2 + (y - y_c)^2 = r_c^2 \end{cases} \qquad (3)$$

In order to solve the above four-equation system, we put the two first equations into the last equation, then we get one equation of two variables φ, θ . We solve the obtained equation according to φ . We get the solution in the form $\theta = \theta(\varphi)$. Take this solution into the first three equations, we obtain the equation of the balde's curvature in the form of parameter (4):

$$\begin{cases} x = x(\varphi) \\ y = y(\varphi) \\ z = z(\varphi) \end{cases} \qquad (4)$$

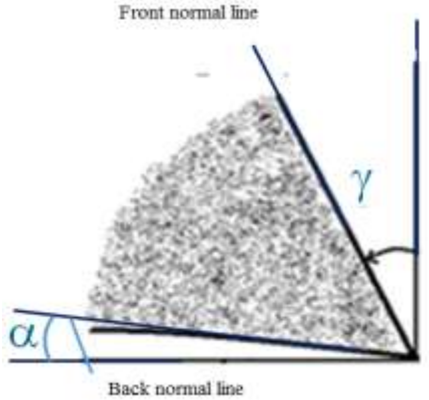

Fig. 3. Front and back angles of scissor blade

Based on the equation (4), in the combination of the front and back angle parameters of the blade, the typical geometrical feature of the curved surface of the blade will be determined.
The normal section of the blade curve of the scissors at its points in Figure 3 represents the curvature profile of the scissors. Thus, the blade curves equation system (4) along with the front angles γ, the back angle α represents the geometry of the blade curved surface of the scissors, Figure 3.

3. Method of accompanying trihedron

By the application of accompanying trihedron [4,..,6], we use a coordinate system representing the geometrical characteristics of the blade, denoted by $O_kX_kY_kZ_k$, origin at the points of the blade curve with coordinates x_k, y_k, z_k in the scissor's coordinate system. The orientation of the coordinate system $O_kX_kY_kZ_k$ is determined so that one axis, for example, X_k axis is the tangent axis of the blade curve. The Z_k axis is the normal axis of the curve, and is the front (back) normal axis in the normal section of blade curve of the scissor when grinding the front (back) surface of the scissor. The Y_k axis is defined according to the right hand rule of the coordinate system (Fig. 4).

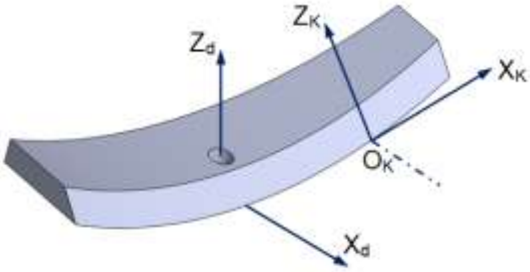

Fig. 4. Accompanying trihedron of the blade

The coordinate system $O_kX_kY_kZ_k$ represents the typical geometrical characteristics of the blade and called accompanying trihedron of the blade, which can be expressed in the scissor's coordinate system $O_dX_dY_dZ_d$ by the homogeneous transformation matrix ${}^{d}A_{pk}$.

$$ {}^{d}A_{pk} = \begin{bmatrix} c_{11k} & c_{12k} & c_{13k} & x_k \\ c_{21k} & c_{22k} & c_{23k} & y_k \\ c_{31k} & c_{32k} & c_{33k} & z_k \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5) $$

The elements of the matrix ${}^{d}A_{pk}$ include the coordinates of the blade points x_k, y_k, z_k, and the c_{ijk} elements of the direction cosine matrix calculated from the equations of blade determination (1),..,(4), and the front angle γ, or the back angle α.

Calling the basic coordinate system $O_0X_0Y_0Z_0$, if the coordinate system of the blade is represented in the basic coordinate system by the ${}^{0}A_d$ matrix, the accompanying trihedron of the blade in the basic coordinate system is expressed as follow:

$$ {}^{0}A_{pk} = {}^{0}A_d \, {}^{d}A_{pk} = \begin{bmatrix} C_{pk} & r_{pk} \\ 0^T & 1 \end{bmatrix} \quad (6) $$

The typical geometrical characteristics of the grindstone is the accompanying trihedron $O_EX_EY_EZ_E$, which is called the grinding accompanying trihedron. Here, the trihedron origin is a conventional point of selection on the profile of the grindstone. For example, for the circular or conical grindstone, the profile is a circle in the cross section perpendicular to the cylindrical axes, Figure 5. The origin of trihedron is selected at a point on the circle. The axis X_E is tangential to the circle and the axis Z_E follows the generatrix of cylinder, and the Y_E axis is defined according to the right hand rules of the coordinate system.

Fig. 5. Grindstone in the shape of cylinder and round cone

At the points on the blade curve, the state (position and direction) of the grindstone trihedron when the machining operation is being performed on the processing object is represented in the basic coordinate system by the matrix ${}^{0}A_{Ek}$ of the form :

$$ {}^{0}A_{Ek} = \begin{bmatrix} c_{Ek11} & c_{Ek12} & c_{Ek13} & x_{Ek} \\ c_{Ek21} & c_{Ek22} & c_{Ek23} & y_{Ek} \\ c_{Ek31} & c_{Ek32} & c_{Ek33} & z_{Ek} \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad {}^{0}A_{Ek} = \begin{bmatrix} C_{Ek} & r_{Ek} \\ 0^T & 1 \end{bmatrix}. \quad (7) $$

Here, the indicator k represents the points on the blade curve.

Normally, the conditions of processing technique determine the relative state of processing tools and processed details, meaning the relative state between the trihedron of grindstone and the blade at the points on the blade curve. Such condition allows to get the binding relation among the elements of the ${}^0A_{pk}$ and ${}^0A_{Ek}$ matrices in the form:

$$\begin{cases} f_j(r_{pk}, r_{Ek}) = 0, \\ g_n(C_{pk}, C_{Ek}) = 0 \end{cases} \quad (8)$$

Depending on the number of freedom degrees of the robot and technical condition of the operation, j=1÷3, corresponding to location conditions, n=1÷3 corresponding to the conditions of the orientation.

For shaping the blade without unwanted cuts, the technical requirement of processing process is that the trihedron $O_{Ek}X_{Ek}Y_{Ek}Z_{Ek}$ of grindstone and blade trihedron $O_kX_kY_kZ_k$ concide at each point of the blade curve of the scissor.

As described in [8], normally, for the 6-dof robots, the trihedron of the stone has six freedom degrees of motion, and the system (8) consists of six equations, in which, the first three equations represent the relation of coordinate system origin and the last three equations represent the orientation.

In order to optimize the structure while processing conditions are still guaranteed during the use of cylindrical grindstone, the following is the method of calculation for the application of the 5-dof robots.

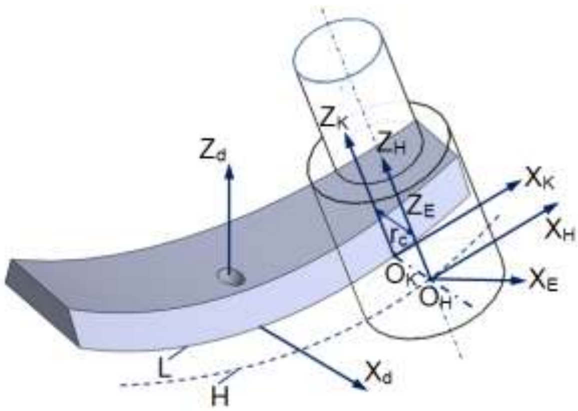

Fig. 6. Contact model of blade and stone surface

For the 6-degree-of-freedom robot, the grindstone trihedron is defined at each position on the blade of the scissor, as shown in Figure 4. On the other hand, the position of the trihedron on the circlar profile of the stone is determined. The 6^{th} freedom degree of the robot is to rotate the stone so that the stone trihedron comes to a position in concidence with the trihedron of the scissor's blade.

Due to the use of cylindrical stones, the points on the circular profile of the stone can make the grinding process on the blade. Call O_H a point on the axis concided with Y_k normal line, a distance equal to the radius r_c of the stone from Z_k axis, see Figure 6. The set of O_H points forms the curve H parallel to the curve L of the scissor's blade.

It can be seen that if the grindstone is moved so that the center axis of the grindstone stands on H and is always parallel to the Z_k axis, then the cutting process of the grindstone on the blade is proper in both location and orientation.

Based on the above comment, the accompanying trihedron of processing details and robots will be taken in the form in which the trihedron of blade has a defined direction in the geometrical shape of blade as stated and the origin of the coordinates lies along the H-line. The grindstone only need determinate by the Z_E axis as the central axis of grindstone.

As mentioned above, the blade trihedron along H will be determined by translating the trihedron $O_kX_kY_kZ_k$ along the bi-normal axis Y_k with the value $-r_c$ (rc - radius of the grindstone). Therefore, the accompanying trihedron of the blade in the basic coordinate system can be represented as follow:

$${}^0A_{Hk} = {}^0A_{pk}\,{}^{pk}A_{Hk} = \begin{bmatrix} C_{Hk} & r_{Hk} \\ 0^T & 1 \end{bmatrix} \quad (9)$$

In order to ensure the processing requirements, it's necessary to follow three conditions of location, specifically: the orgin of grindstone trihedron concides with each point O_H on the H curve and two conditions about the orientation of the central axis of grindstone must be parallel to the Z_k axis. Hence, the equation (8) should be taken into the form of five equations, including j=1÷3 corresponding to the condition of position, n=1÷2 corresponding to orientation conditions.

$$\begin{cases} f_j(r_{Hk}, r_{Ek}) = 0, \\ g_n(C_{Hk}, C_{Ek}) = 0 \end{cases} \quad (10)$$

With the five above conditions, we only need to use a 5-dof robot and by the application of the transformed accompanying trihedron, we can set the motion condition of robot to ensure the blade grinding technology. The following section will establish kinematic equations and design the motion trajectory for robot.

III. ROBOT KINEMATIC EQUATIONS

Figure 7 introduces one of the 5- dof robots used for the blade grinding of the curved-tip medical surgical scissor in the study.
The figure shows the five links of the robot, in which, the 5th link with the use of the grindstone-a processing tool will be connected.

In order to use the robot for grinding process, it is necessary to design the motion trajectory for robot. During the trajectory design, in order to ensure that the motion of the robot can exactly perform the processing operation, firstly, it is necessary to rely on the kinematic structure of the robot, determine the status of end-effector link based on the kinematic structure and establish the robot kinematic equations.

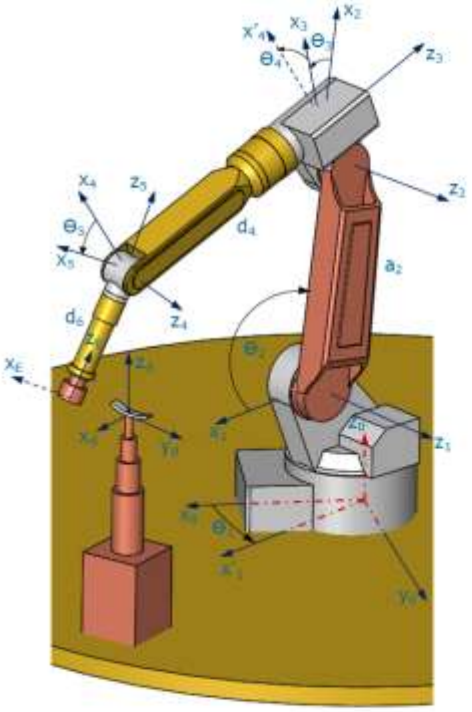

Fig. 7. Kinematic structure, coordinate systems of robot

By the application of the Denavit-Hartenberg (DH) method, the coordinate systems of the links and basic coordinates are established. Table 1 shows the kinematic parameters DH.

Table 1: Kinematic parameters DH

Joint	θ_i	d_i	a_i	α_i
1	θ_1	d_1	a_1	α_1
2	θ_2	d_2	a_2	0
3	θ_3	d_3	a_3	α_3
4	θ_4	d_4	0	α_4
5	θ_5	0	0	α_5
E	0	d_E	0	0

By the application of the homogeneous transformation matrix, the homogeneous transformation matrices on the kinematic sequence of the robots ${}^0A_1(q_1)$, ${}^1A_2(q_2)$,.., ${}^4A_5(q_5)$, ${}^5A_E$ can be calculated. The homogeneous transformation matrix ${}^0A_E(q)$ of the end-effector link is defined by:

$$ {}^{0}A_E(q) = {}^{0}A_1(q_1)\ldots{}^{4}A_5(q_5)\,{}^{5}A_E \qquad (11) $$

In which:

$$ q = [q_1, q_2, .., q_5]^T = [\theta_1, \theta_2, .., \theta_5]^T \qquad (12) $$

is the jointed coordinate vector of the robot.

With the structure of cylindrical grindstone, and the calculation method in section 3, the trihedron $O_EX_EY_EZ_E$ of the grindstone is shown in Figure 6, 7. As shown in Figure 7, the coordinate system $O_EX_EY_EZ_E$ is defined in the basic coordinate system by matrix ${}^{0}A_E(q)$. Thus, by replacing the elements of the matrix ${}^{0}A_{Ek}(r_{Ek},C_{Ek})$ in the the system of equations (10) by the elements of the end-effector's state matrix ${}^{0}A_E(q)$ by (11), we get the system of equations that express the relationship between the joint coordinates q of the robot with the characteristic parameters of the blade x_k, y_k, z_k, c_{ijk} (i,j=1,2,3).

$$ \begin{cases} f_j(r_{Hk}, q) = 0, & j = 1,2,3 \\ g_n(C_{Hk}, q) = 0, & n = 1,2 \end{cases} \qquad (13) $$

Here, the first three equations of (13) represent the position of O_H at each point on the H curve. The last two equations are the condition for the Z_E axis to be parallel to the Z_k axis of the blade trihedron at each point on H. Specifically, the third column vector of the direction cosine matrix C_{Ek} is orthogonal with the first and second column vectors of the direction cosine matrix C_{Hk}.

The L-blade curve of the scissor is divided by N points (k = 1, .., N), accordingly, the H line also has N points, respectively. The processing process can be represented as motion of the blade trihedron $O_kX_kY_kZ_k$, thus, the homogeneous trihedron $O_HX_HY_HZ_H$ comes consecutively between the points k = 1, .., N. Under processing conditions, the relative velocity between the grindstone surface and processing surface is the motion velocity of the trihedron orgin O_k located consecutively among the points, in tangential direction to the blade curve of the scissor, marked by v_r and predefined. As such, the ${}^{d}A_{pk}$ state matrix of blade trihedron with the elements x_k, y_k, z_k, c_{ijk} (i,j=1,2,3) is defined by the system of blade determination equations (1) , .., (4), and the front angle γ, or the back angle α, and the velocity v_r. In general, v_r can be demonstrated as a function of time $v_r=v_r(t)$, therefore, so the elements x_k, y_k, z_k, c_{ijk} are functions of t. Therefore, the sub-matrices r_{pk}, C_{pk} of the ${}^{O}A_{pk}$ matrix has elements that are also functions of t is defined. By this way, the position and direction of the trihedron $O_HX_HY_HZ_H$ are determined, and accordingly, the sub-matrices $r_{Hk}(t)$, $C_{Hk}(t)$, are also determined.
By such demonstration, from the system of equations (13), we obtain the kinematic system of the robot with $r_{Hk}(t)$, $C_{Hk}(t)$.

$$ \begin{cases} f_j\left(r_{Hk}(t), q\right) = 0, & j = 1,2,3 \\ g_n\left(C_{Hk}(t), q\right) = 0, & n = 1,2 \end{cases} \qquad (14) $$

IV. ROBOT'S TRAJECTORY

The robot trajectory is obtained by solving the kinematic equation system (14) to compute q when predetermined $r_{Hk}(t)$, $C_{Hk}(t)$. First of all, we choose the coordinate system of the machining-detail clamping table, that is the coordinate system of the blade, the symbols $O_dX_dY_dZ_d$, determined in the base coordinate system by the parameters x_d, y_d, z_d, rotx, roty, royz. With these parameters, the ${}^{0}A_d$ matrix will be computed.

In order for ${}^{d}A_{pk}$ matrix elements to be computed according to the equation systems of previous angles γ, or lateral angles α, in the scissor coordinate system $O_dX_dY_dZ_d$, we give the center's coordinates of the and radius of the cylindrical surface, x_c, y_c, z_c, r_c, center's coordinates and radius of the toroidal surface x_e, y_e, z_e, r_e, and radius of the circle of the cross section of toroidal surface r_s.

For the relative speed between the grinding stone and the processing surface, called grinding speed $v_r(t)$ given, the angle $\varphi(t)$ is defined. From this we can calculate the coordinates $x_k(t)$, $y_k(t)$, $z_k(t)$ of the points O_H. Based on the previous angle γ, or lateral angle α, along with the equation systems (1),..,(4), using the formulas in differential geometry we can find the tangent, normal and linear vectors of the blade trihedron at the points k, meaning that it is possible to find the elements $c_{ijk}(t)$ of the direction cosine matrix $C_{Hk}(t)$.
With the calculated parameters solved by the robot kinematic equations (14), we can calculate the trajectory of the robot.

V. CALCULATION AND SIMULATION RESULT

5.1 Calculation parameters

Below is the kinematic calculation, the trajectory design for the robot to perform the grinding process of the front of the blade.

Table 2 shows the kinematic parameters of the robot.
Table 3 shows the scissor coordinate system positioning parameters in base coordinates.
Table 4 shows the center's coordinates and radius of the cylindrical surface in the scissor coordinate system $O_dX_dY_dZ_d$.
Table 5 shows the center's coordinates and radius of the toroidal surface, and radius of the circle of the cross section of toroidal surface in the $O_dX_dY_dZ_d$ scissor coordinate system.
The unit of long values is meters (m). Speed (move knife) when grinding is v_r = 0.3m/s. Speed of grinding v_c is about 30m/s.

Table 2. DH dynamic parameters table

Joint	θ_i	d_i	a_i	α_i
1	θ_1	0.415	0.160	90^0
2	θ_2	0.040	0.580	0
3	θ_3	-0.040	0.125	90^0
4	θ_4	-0.680	0	-90^0
5	θ_5	0	0	90^0
E	0	-0.348	-0.020	0

Table 3. Table of scissor coordinate system positioning parameters

x_d	y_d	z_d	rotx	roty	royz
1.0	0	0.065	0	0	$5\pi/18$

Table 4. Center's coordinates and radius of the cylindrical surface

x_c	y_c	z_c	r_c
-0.54372	-0.01735	0	0.55

Table 5. Center's coordinates and radius of the toroidal surface, and radius of the circle of the cross section of toroidal surface.

x_e	y_e	z_e	r_e	r_s
0	0.012	0.1642	0.1652	0.175

5.2 Calculations and simulation ersult

The scissor blade curvature profile in the scissor coordinate system is shown in Figure 8. The unit on the coordinate axes is mm. Fig. 9 shows the position of the links over time. Fig. 10 shows an image of the blade grinding simulation.

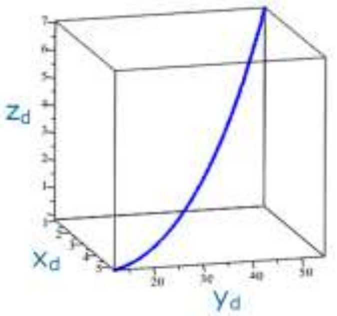

Fig. 8. Scissor blade curvature profile.

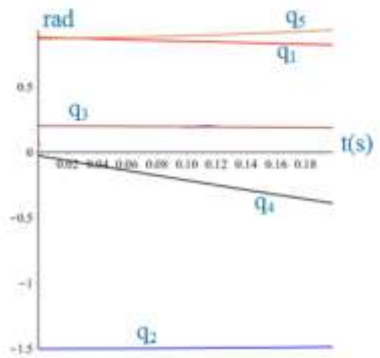

Fig. 9. Position of the links over time

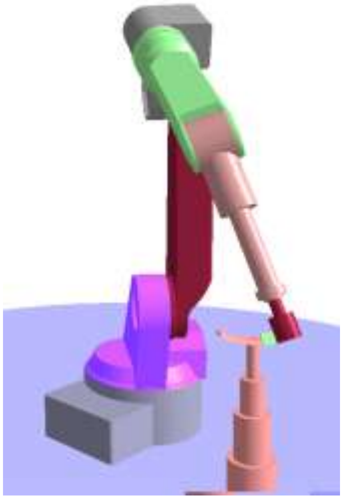

Fig. 10. Simulate grinding process

VI. CONCLUSION

The paper has established an equation system that define blade curve in the form of parameters to apply grinding on the 5-dof robots. The method presented can be applied when grinding for kinds of scissor with different geometrical parameters. Research result is applied calculation of numerical simulation and manipulation process simulation for intuitive and reliable images. The result obtained is perfectly matched with the simulation result when using the 6-degree robot. With conical grinding wheels, it is necessary to add some variations and calculations in order to apply the 5-degree-of freedom robots, which will be announced in the next work.

REFERENCES

[1]. George Christoudias, Scissors – US7176866-B1, (2001).
[2]. Jerorne E Hulse, Automatically sharpening shears - US 874847A , (1907).
[3]. Thomas E. Devlin, Kristin W. Grube Cutting blade assembly for a surgical scissors US 5562693 A; (1996).
[4]. Thomas Y. Lo, Franklin Tao, Tolentino Escorcio, Kirk H. Packo, For cutting tissue of an eye US 5275607 A, (1994).
[5]. Banh Tien Long, Le Van Tham. Research on surface shaping motion, make equation for curved blade curvature calculation for medical use. Apply with scissor Moayo 160, curved head, jagged/sharp peak - Vietnam Mechanical Journal, 04/2012, p. 80-88.
[6]. Phan Bui Khoi, Bui Ngoc Tuyen, Le Van Tham. Modeling of the blade geometry of curved medical scissor, Journal of Science and Technology, 109 (2015) p. 61-66.
[7]. Phan Bui Khoi, Le Van Tham, Bui Ngoc Tuyen. Research on cutting force of medical scissors and measures to improve the quality of work of scissors. Proceeding of 3rd National Conference on Science and Technology in Mechanics. 4/2013, p.
[8]. Le Van Tham, Phan Khoi Bui, Bui Ngoc Tuyen, Cu Xuan Hung, Nguyen Duc Toan. Design of motion trajectory of robots using a curved-head surgical grinding. Proceeding of 2nd National Conference on Mechanics and Automation. Hanoi, 2016, pp. 467-472.
[9]. Phan Bui Khoi (2009). Calculation and simulation of the program motion of mechanisms of relative manipulation". Journal of Science and Technology, Vietnam Aacademy of Science and Technology. № 3, vol. 47, pp. 19-28.
[10]. Phan Bui Khoi, Tran Minh Thuy, Bui Van Hanh (2007). Kinematic calculation of welding robot dynamics with mobile background. Proceedings of the 8th National Conference on Mechanics. Vol 1, p. 280-293.
[11]. Phan Bui Khoi, Nguyen Thi Quyen. Simulation of operation of the robot working with spherical parallel structure machine table. Proceedings of the National Conference Machine and Structure 2015. p. 131-145.

*Phan Bui Khoi " Application of the 5-dof robot for grinding the cutting blade of the curved-tip medical surgical scissor." American Journal of Engineering Research (AJER) 6.8 (2017): 103-111.