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# Kinematic analysis of a SCARA robot for deburring of rectangular paths

K.Chinmayi, PVS Subhashini , G.Venkata Rao & NVSRaju

**Abstract**— SCARA (Selective Compliance Articulated Robot Arm) is a popular manipulator used for the applications like pick and place, loading and unloading, assembly, etc. In the recent time SCARA is also applied for deburring, 3D printing, etc. The present work objective is to analyze the kinematics of a SCARA robot where its application is deburring of rectangular paths, it is assumed that the forces encountered between the end effector and workpiece are negligible. In the present work SCARA robot is modeled in NX, using motion simulation, kinematics are analyzed and also mathematical analysis of the SCARA robot is done using MATLAB. Later a comparison is made between the NX CAD simulation and mathematical analysis using MATLAB, and concluded with reasonable arguments.

**Index Terms**—CAD analysis, Deburring, Kinematics, MATLAB, NX, Rectangular paths, SCARA

## 1 Introduction

INDUSTRAIL robot anatomy consists of a manipulator and wrist with an end effector to execute a specific function. One such manipulator is a SCARA(selectiive compliance articulated robot arm) with 3 revolute and 1 prismatic joint. This manipulator is very popular and its kinematics an dynamics are already derived and presented [1-3].

SCARA manipulator is primarily used where the operation requires high accuracy, and less operating time. The special capability of the SCARA manipulator is to pick industrial components with smooth motion, precision and high speed. SCARA robots are comparatively inexpensive and highly versatile. In the present scenario SCARA robots are automated solution for electronic assembly. Due to their design aspects SCARA robots are regularized for use in handling and assembly. SCARA is applied to pick and place type operations, automated palletizing, and de-palletizing operations, assembly, machining operations etc. Fig1. presents the structure of a SCARA manipulator.

The rest of the paper is organized as Literature survey, CAD modeling and analysis of SCARA manipulator, kinematic analysis of SCARA manipulator, results and discussions with a conclusion.

## 2 Literature Survey

Panchanand Jha et al. [4] Proposed structured artificial neural network (ANN) model to find the inverse kinematics solution of a 4-dof SCARA manipulator and suggested that to know joint angles artificial neural network is the best tool.

Talib eh. Elaikh et al.[5] presented the vibration analysis of the SCARA robot in order to improve the performance. The results obtained from this analysis are considered to be appropriate for vibration analysis and also for evaluating the kinematic analysis.

M.Taylan et.al [6] developed a mathematical model of a SCARA robot including servo motor which is used for pick and place operations. The Performance of the robot was confirmed practical experiments with mathematical simulation.

Ali medjebouri et al.[7] presented a method of disturbance rejection control in order to control the movement of the SCARA robot arm.

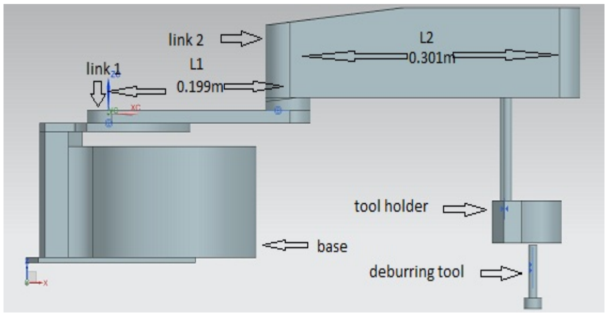


Fig.1. Front view of the SCARA robot

## 3 CAD Modelling And Analysis Of Scara Robot

### 3.1 Part Modelling

NX CAD software is used for modeling SCARA robot. SCARA robot consists of base, link 1, link 2, tool holder, deburring tool as shown in Fig.1.

These parts are first modelled in 2D and later converted into 3D using extrude, revolve commands.

Commands used for modelling the parts in 2D SIMENS NX

- *P.G.student ,Department of Mechanical Engineering, Vasavi college of Engineering, Hyderabad 9573652858.E-mail:kchinmayi92@gmail.com*
- *Assistant professor, Department of Mechanical Engineering ,Vasavi college of Engineering ,Hyderabad,9866802894,E-mail:siva726@yahoo.co.in*
- *Former Professor in Mechanical Engineering,Vasavi college of Engineering,Hyderabad,9848159473,E-mail:gvrao@yahoo.com*
- *Professor, Department of Mechanical Engineering, JNTUH Telangana, India enviousraju@gmail.com*

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are circle, line, trim, extrude, fillet, Boolean operations and rectangle.

Fig.2 presents the base of a SCARA robot which is fixed.

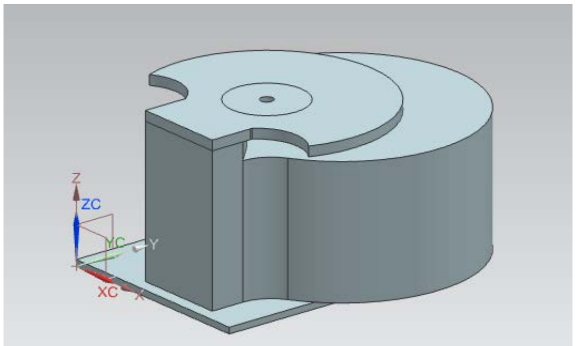


Fig. 2. Fixed base

Fig.3 presents link1. Length of the link is 0.199m, to construct the link first a rectangle of 0.199m is drawn and extruded in the opposite direction as seen above the distance between the two centers of the circles are 0.199m.this makes a rotatory motion relative to base.

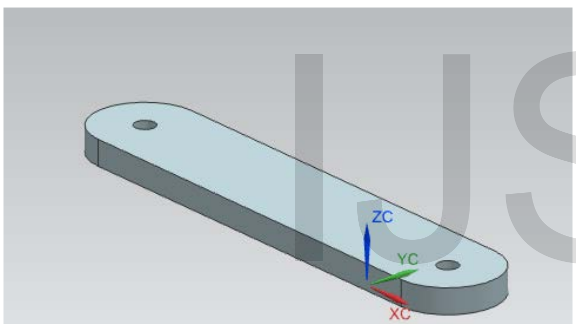


Fig. 3. Link 1

Fig.4 presents link 2 ,the distance between the two centers of the link is 0.301m to construct the link commands used are chamfer,circle,extrude. This makes a rotatory motion relative to the link 1.

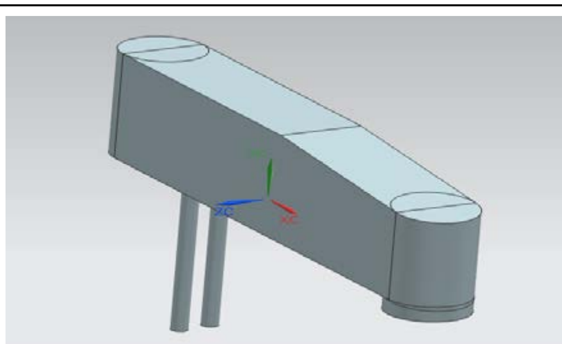

Fig. 4. Link 2

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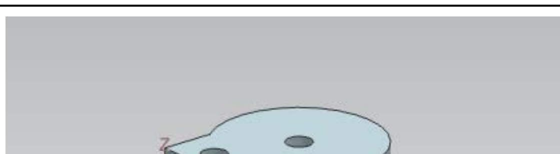

Fig.6 presents a tool which makes a translational motion with tool holder.

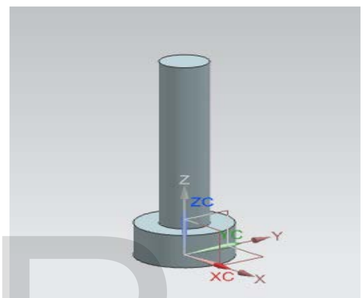


Fig. 6. Deburring tool



### 3.2 Assembly

Assembly is the combination of base, link 1, link2, tool holder and tool.

This is done by using commands such as concentric, touch align and distance between the centers.

Fig.6 shows the assembly of a SCARA robot.

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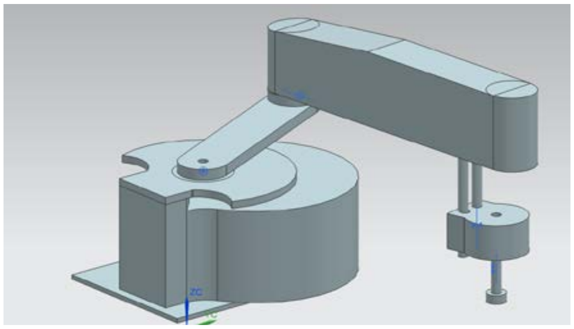

Fig 6. Assembly

## 4 Kinematic Analysis

Input data contain PX,PY,link lengths ,VX, VY, accX and accY, where as velocities and accelerations in x and y direction are calculated from the the differentiation with respect to time using the values of PX ,PY and VX VY. Link lengths are selected based on the singularity condition.

Figure 7 shows a rectangle divided into 20 points to generate the data PX, PY as shown in table 1. Dimensions of the rectangle is 0.60*0.40m.

TABLE 1

Shows The Values Of Px And Py Which Are The Input Parameters In Matlab Program

| time | PX | PY |
|---|---|---|
| 0 | 0.25 | 0 |
| 0.5 | 0.262 | 0 |
| 1 | 0.274 | 0 |
| 1.5 | 0.286 | 0 |
| 2 | 0.298 | 0 |
| 2.5 | 0.31 | 0 |
| 3 | 0.31 | 0.008 |
| 3.5 | 0.31 | 0.016 |
| 4 | 0.31 | 0.024 |
| 4.5 | 0.31 | 0.032 |
| 5 | 0.31 | 0.04 |
| 5.5 | 0.298 | 0.04 |
| 6 | 0.286 | 0.04 |
| 6.5 | 0.274 | 0.04 |
| 7 | 0.262 | 0.04 |
| 7.5 | 0.25 | 0.04 |
| 8 | 0.25 | 0.032 |
| 8.5 | 0.25 | 0.024 |
| 9 | 0.25 | 0.016 |
| 9.5 | 0.25 | 0.008 |
| 10 | 0.25 | 0 |

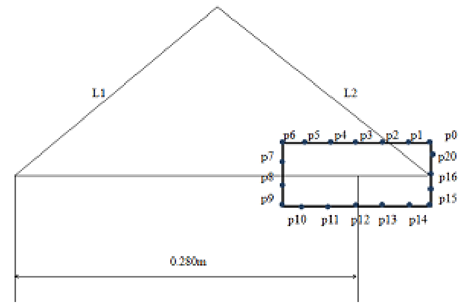


Fig. 7.Top view of SCARA ( Rectangular path)

## 5 Results and discussions

Table 2 presents the angular displacements of joint 1 and joint 2 which are obtained from the MATLAB.

TABLE 2

Teeta Values For Joint 1 And Joint 2

| time | Θ1 | Θ2 |
|---|---|---|
| 0 | 83.36304 | 55.58836 |
| 0.5 | 80.25841 | 59.07949 |
| 1 | 77.24542 | 62.6027 |
| 1.5 | 74.30309 | 66.16755 |
| 2 | 71.41318 | 69.78371 |
| 2.5 | 68.55934 | 73.46132 |
| 3 | 67.05664 | 73.49325 |
| 3.5 | 65.50709 | 73.589 |
| 4 | 63.91282 | 73.74848 |
| 4.5 | 62.27604 | 73.97154 |
| 5 | 60.599 | 74.25796 |
| 5.5 | 63.13 | 70.59708 |
| 6 | 65.66691 | 67.00146 |
| 6.5 | 68.22187 | 63.4613 |
| 7 | 70.80797 | 59.96741 |
| 7.5 | 73.43986 | 56.51087 |
| 8 | 75.53367 | 56.17991 |
| 8.5 | 77.57748 | 55.92162 |
| 9 | 79.56659 | 55.73664 |
| 9.5 | 81.49653 | 55.62545 |
| 10 | 83.36304 | 55.58836 |

Table 3 presents the angular velocities of joint 1 which are obtained from the MATLAB.

TABLE 3

SHOWS THE VELOCITY OF JOINT 1 IN MATLAB AND NX

| time | V1MATLAB | V1NX |
|---|---|---|
| 0 | 6.316651 | 6.300874 |
| 0.5 | 6.110079 | 6.117642 |
| 1 | 5.948848 | 5.936195 |
| 1.5 | 5.826529 | 5.815227 |
| 2 | 5.738548 | 5.777076 |
| 2.5 | 2.957202 | 4.533016 |
| 3 | 3.052946 | 3.096127 |
| 3.5 | 3.144539 | 3.145997 |
| 4 | 3.231799 | 3.233231 |
| 4.5 | 3.314587 | 3.274358 |
| 5 | 5.063855 | 3.977374 |
| 5.5 | 5.063994 | 5.073834 |
| 6 | 5.087707 | 5.07966 |
| 6.5 | 5.136471 | 5.127454 |
| 7 | 5.21278 | 5.177219 |
| 7.5 | 4.234436 | 4.74951 |
| 8 | 4.139206 | 4.096821 |
| 8.5 | 4.03446 | 4.037524 |
| 9 | 3.920513 | 3.923482 |
| 9.5 | 3.797812 | 3.796476 |
| 10 | 0 | 0 |

Table 4 presents the angular velocities of joint 2 which are obtained from the MATLAB.

TABLE 4

SHOWS THE VELOCITY OF JOINT 2 IN MATLAB AND NX

| s.no | V2MATLAB | V2NX |
|---|---|---|
| 0 | 0.640013 | 0.649 |
| 0.5 | 0.901058 | 0.897 |
| 1 | 1.136017 | 1.142 |
| 1.5 | 1.351199 | 1.356 |
| 2 | 1.551744 | 1.457 |
| 2.5 | 2.957202 | 0.755 |
| 3 | 2.925246 | 2.907 |
| 3.5 | 2.889264 | 2.891 |
| 4 | 2.8492 | 2.850 |
| 4.5 | 2.805029 | 2.826 |
| 5 | 2.330127 | 0.663 |
| 5.5 | 2.189114 | 2.119 |
| 6 | 2.044921 | 2.047 |
| 6.5 | 1.894576 | 1.898 |
| 7 | 1.734706 | 1.809 |
| 7.5 | 3.500392 | 0.042 |
| 8 | 3.549709 | 3.577 |
| 8.5 | 3.590993 | 3.594 |
| 9 | 3.624219 | 3.627 |
| 9.5 | 3.649469 | 3.648 |
| 10 | 0 | 0.000 |

Table 5 presents the angular accelerations of joint 1 which are obtained from the MATLAB.

TABLE 5

SHOWS THE ACCELERATION OF JOINT 1 IN MATLAB AND NX

| s.no | acc1MATLAB | acc1 NX |
|---|---|---|
| 0 | 0.000 | 0.000 |
| 0.5 | 2.079 | 0.370 |
| 1 | 1.774 | 0.243 |
| 1.5 | 1.534 | 0.311 |
| 2 | 18.971 | 2.127 |
| 2.5 | 1.016 | 10.841 |
| 3 | 1.095 | 3.330 |
| 3.5 | 1.176 | 0.262 |
| 4 | 1.257 | 0.253 |
| 4.5 | 5.094 | 14.875 |
| 5 | 1.038 | 33.766 |
| 5.5 | 1.143 | 2.129 |
| 6 | 1.272 | 0.109 |
| 6.5 | 1.432 | 0.179 |
| 7 | 16.851 | 1.303 |
| 7.5 | 3.032 | 4.292 |
| 8 | 2.855 | 0.822 |
| 8.5 | 2.667 | 0.309 |
| 9 | 2.472 | 0.228 |
| 9.5 | 2.912 | 0.253 |
| 10 | 0.000 | 0.000 |

Table 6 presents the angular accelerations of joint 2 which are obtained from the MATLAB.



TABLE 6

SHOWS THE ACCELERATION OF JOINT 2 IN MATLAB AND NX

| s.no | acc2MATLAB | acc2 NX |
|---|---|---|
| 0 | 0 | 0.000 |
| 0.5 | 4.252607 | 0.498 |
| 1 | 3.66184 | 0.429 |
| 1.5 | 3.195579 | 0.616 |
| 2 | 23.50191 | 5.382 |
| 2.5 | 1.895903 | 18.788 |
| 3 | 2.02942 | 4.466 |
| 3.5 | 2.16074 | 0.116 |
| 4 | 2.288219 | 0.124 |
| 4.5 | 3.864983 | 6.735 |
| 5 | 1.992479 | 1.713 |
| 5.5 | 2.180712 | 6.262 |
| 6 | 2.41386 | 0.438 |
| 6.5 | 2.704939 | 0.454 |
| 7 | 18.5878 | 2.708 |
| 7.5 | 5.436159 | 20.257 |
| 8 | 5.173252 | 6.985 |
| 8.5 | 4.882939 | 0.124 |
| 9 | 4.571119 | 0.066 |
| 9.5 | 8.062394 | 0.043 |
| 10 | 0 | 0.000 |

Figure 8 presents a rectangular path formed from the angular diaplacement of join 1 and joint 2.

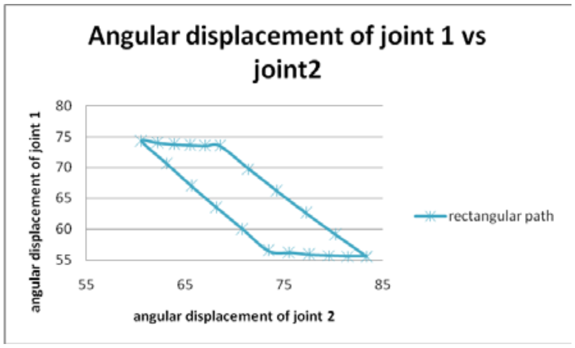


Figure 8. Angular displacement of joint 1 vs joint 2

Figure 9 presents angular displacement of joint 1 with respect to time in MATLAB and NX. From this it is observed the direction and magnitudes are same both in MATLAB and NX. And joint1 is changing for every 5 seconds.

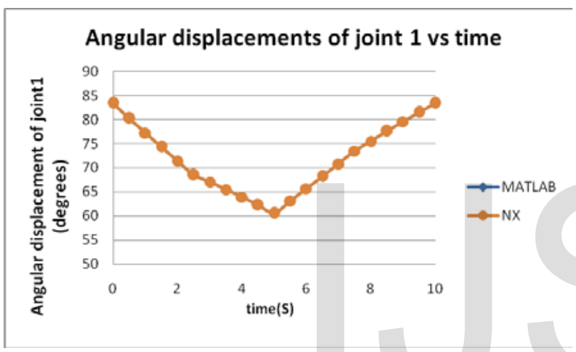


Figure 9. Θ1 vs time

Figure 10 presents angular displacement of joint 2 with respect to time in MATLAB and NX. From this it is observed the direction and magnitudes are same both in MATLAB and NX .And joint 2 is changing for every 2. 5 seconds, displacements are linear from 2.5-5 seconds and 7.5-10 seconds.

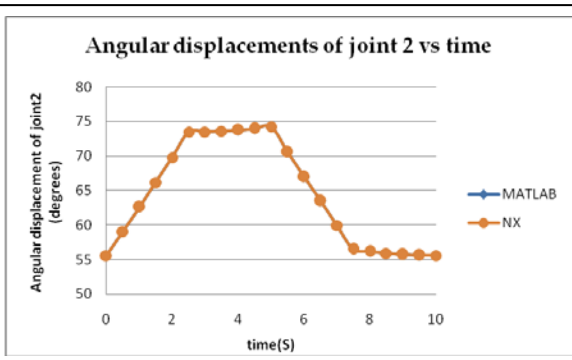


Figure 10. Angular displacement of joint 2 vs time

Figure 11 presents angular velocity of joint 1 which is compared both in MATLAB and NX , this graph presents that angular velocity changes with change in the direction.

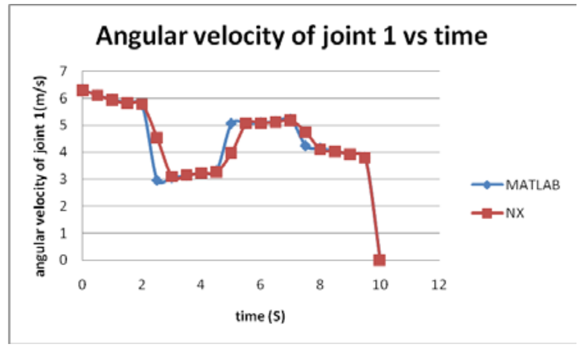


Figure 11. Angular velocity of joint 1 vs time

Figure 12 presents angular velocity of joint 2 which is compared both in MATLAB and NX ,this graph presents that angular velocity changes with change in the direction.

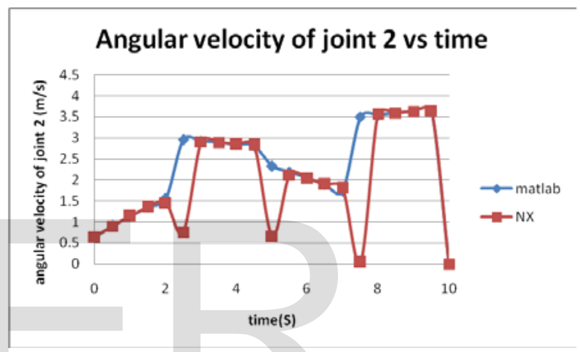


Figure 12. Angular velocity of joint 1 vs time

Figure 13 presents angular acceleration of joint 1 which is compared in both MATLAB and NX, acceleration changes with the change in direction.

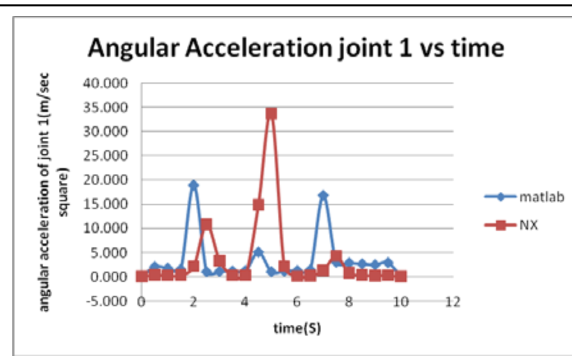


Figure 13. Angular Acceleration joint 1 vs time

Figure 14 presents angular acceleration of joint 2 which is compared in both MATLAB and NX,acceleration changes with the change in direction

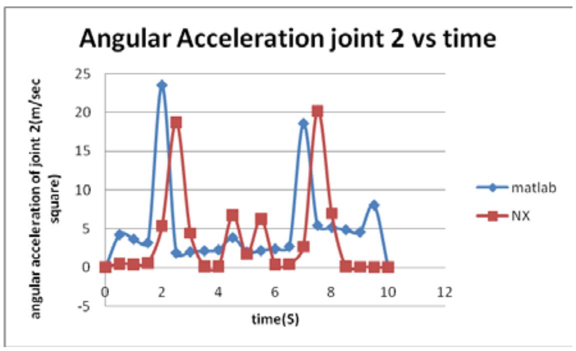


Figure 14 Angular acceleration of joint 2 vs time

## Nomenclature

| | |
|---|---|
| PX | displacement in x-axis(m) |
| PY | displacement in y-axis(m) |
| VX | velocity in x axis(m/s) |
| VY | velocity in y axis(m/s) |
| acc X | acceleration in x-axis(m/s2) |
| acc Y | acceleration in y-axis(m/s2) |
| $L_1$ | length of link 1 |
| $L_2$ | length of link 2 |
| ϴ1 | angular displacement of joint 1(rad) |
| ϴ2 | angular displacement of joint 2(rad) |
| $V_1$MAT | angular velocity of joint 1 in MATLAB |
| $V_2$MAT | angular velocity of joint 2 in MATLAB |
| $acc_1$MAT | angular acceleration of joint 1 matlab |
| $acc_2$MAT | angular acceleration of joint MATLAB |
| $V_1$NX | angular velocity of joint 1 in NX |
| $V_2$NX | angular velocity of joint 1 in NX |
| $acc_1$NX | angular acceleration of joint 1 NX |
| $acc_2$NX | angular acceleration of joint NX |

## 6 Conclusion

SCARA robot is modeled in NX, motion simulation is carried out for analyzing the rectangular paths. Mathematical analysis of the SCARA robot is used MATLAB for the same rectangular path and compared for verification. It is observed that with respect to joint velocities and accelerations there is variation at the time of 2.5 S, 5S, 7.5S, this is because when ever there is change in the direction of the movement of the tool perpendicularly this change is observed. This difference may be reduced by providing the offset at the points where there is a change in direction of movement. In future work this modification has to implement for complete verification.

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