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STATIC ANALYSIS OF EIGHT DEGREES OF FREEDOM ARTICULATED ROBOT ARM UNDER VARYING LOAD CONDITIONS

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Abstract

Current trends such as shorter product lifecycles, reduced time-to-market and mass-customization require new paradigms and approaches for production lines and machines. In the long term, production and manufacturing companies will only be able to survive in the face of increasing globalization if they can react flexibly and quickly to changing customer and market demands. New paradigms and approaches are waiting to fulfill these requirements, but their implementation requires completely new technologies. Reconfiguration, both at machine and control technology level is a promising candidate to achieve the flexibility required by these paradigms by technical means. This makes a shift from centrally controlled, highly interlinked, and often tightly interlocked production systems to distributed, modular, collaborative components essential.

In this paper concept of eight-degree of freedom robot arm is discussed. This will allow a wide range of arm positions for any given target position, thus giving a great flexibility of motion. Motion can be governed by additional constraints, for more realistic motion than conventional six-degree of freedom systems, which have only a finite number of solutions for a target position. The paper presents an approach using modeling and a static analysis of eight axis robotic arm that consider its chains and mechanism.

Keywords: Robot arm, Degrees of freedom, Static analysis, Natural frequency.

1. INTRODUCTION

The main goal of the project is to make a modal & analyze the eight axis unique robot arm for industrial applications. The robot arm is probably the most mathematically complex to design theoretical, with the help of CAD technology we could design with precise method.

This study presents the processes undertaken in the modeling and analysis of eight degrees of freedom (DOF) robot arm. The eight degrees of freedom robotic arm provides wide trajectory coverage over the three-dimensional space around the base. This will allow a wide range of arm positions for any given target position, thus giving a great flexibility of motion. Motion can be governed by additional constraints, for more realistic motion than conventional six-degree of freedom systems, which have only a finite number of solutions for a target position.

The eight degrees of freedom are achieved by combining additional two degrees of freedom to the six degrees of freedom articulated robot arm. The additional two degrees of freedom are, one is the reciprocating motion of revolving plate with respect to link1 and the other motion is again the reciprocating motion of gripper with respect to link 5.

2. Literature Review

Gabriel Munteanu [1] discussed about computer and control system technologies have significantly increased the control of the kinematic chains in terms of precision of positioning. Highly accurate kinematic chains or adjustment of the functioning systems to achieve suitable precision are still required in actual applications. The paper presents an original approach using an analysis of accuracy of 5R robotic structure that considers its chains and mechanisms. The results corresponding to the entire structure are presented as well as the final indication about the characteristics to be improved. The analysis comprises the assessment from the static point of view and natural frequencies.

Maxine Emerich [2] mentioned the development of a six degree-of-freedom articulated robotic arm to automatically manufacture electrochromic nano-scale films on glass slides. The development of equations for forward and inverse kinematics of the robot arm is described. From the kinematic equations the geometry of the robot is created. The forward and inverse kinematics is used to design the robot links. Using the selected link geometry, torque values are calculated for each robot joint. Motors to support the expected torques are chosen from a commercial supplier. Finally, an end-effectors is designed that attaches to the robotic arm and which holds and rotates the slides that are used to make nano-films.

3. Software Feasibility

In the software feasibility, the best program is selected to solve the needs. Here PRO-E is used for modeling of the robot arm and the ANSYS for the analysis of the robot arm

4. Computer Aided Modeling Of Robot Arm

For the functional structure, a virtual model was built introducing all the parts and components, linked to model the robotic system.[1]. In the robot kinematics, the gripper can be moved where ever is needed using rotation of links and joints. For this purpose, links and joints are accepted as a coordinate system individually.

Components of the robot arm are

[1] Base
[2] Revolving Plate
[3] Link 1
[4] Link 2
[5] Link 3
[6] Link 4
[7] Link 5
[8] Gripper
[9] Controller 1
[10] Controller 2
[11] Controller 3
[12] Controller 4

5. Assembly Of Robot Arm

As combine features into parts, combine parts into assemblies. Assembly mode in Pro/E enables to place component parts and subassemblies together to form assemblies. Resulting assemblies can be modified, analyzed, or reoriented.

Robot arm assembly is shown below

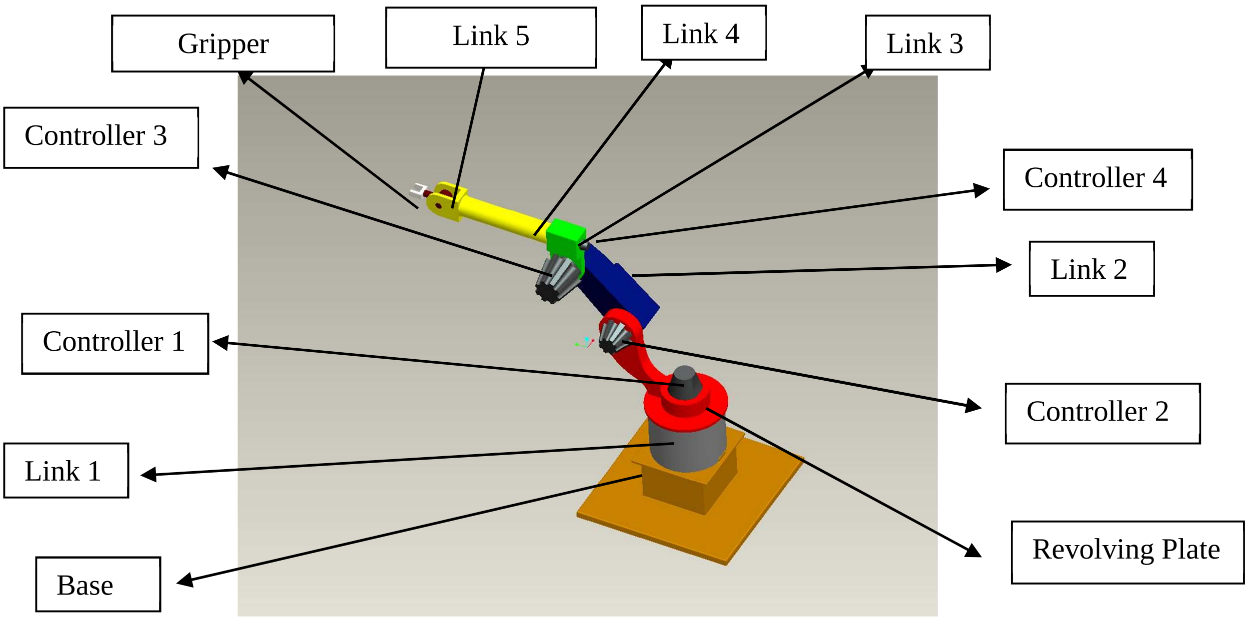

Fig. 1 Assembly of Robot Arm

The eight degrees of freedom are achieved by combining additional two degrees of freedom to the six degrees of freedom articulated robot arm. The additional two degrees of freedom are, one is the reciprocating motion of revolving plate with respect to link1 and the other motion is again the reciprocating motion of gripper with respect to link 5.

In mechanics, degrees of freedom are the set of independent displacements and/or rotations that specify completely the displaced or deformed position and orientation of the body or system [2].

6. Motions of Robot Arm

Axis 1

This axis, located at the robot base, allows the robot to rotate from right to left. This is the relative motion of revolving plate with respect to link1. This allows the revolving plate to revolve about its own axis in the clockwise direction in the first half cycle of motion of robot arm and in the counter clockwise direction in the return half cycle of motion of robot arm. This sweeping motion extends the work area to include the area to either side and behind the arm. This axis allows the robot to spin up to a 90 degree.

Axis 2

This axis is also located at the robot base, allows the robot to move in the upward and downward. This is the relative motion between the revolving plate and link 1. This allows the motion of revolving plate in the upward direction along the axis of joint between the revolving plate and link 1 in the first half cycle of motion of robot arm and in the downward direction along the same axis of joint in the return half cycle of motion of robot arm for better part assessment.

Axis 3

This axis is located at the robot linkage. This is the relative motion of link 2 with respect to revolving plate. This axis allows the link 2 of the robot arm to extend forward and backward. It is the axis powering the movement of the entire robot arm. During the first half cycle of motion of robot arm the link 2 is rotate in the counter clockwise direction along the axis of joint of link 2 and the revolving plate and during the next return half cycle it rotates in the clockwise direction along the same axis of joint

Axis 4

The axis extends the robot's vertical reach. This is the relative motion of link 3 with respect to link 2. It allows the link 3 to raise and lower. During the first half cycle of motion of robot arm the link 3 is rotate in the clockwise direction along the axis of joint of link 3 and the link 2 and during the next return half cycle it rotates in the counter clockwise direction along the same axis of joint. On some articulated models, it allows the upper arm to reach behind the body, further expanding the work envelope. This axis gives the upper arm the better part access.

Axis 5

This axis aids in the positioning of the end effecter and manipulation of the part known as the wrist roll. It is the relative motion between the link 4 and the link 3. It rotates the link 4 in a circular motion i.e. it revolves about its own axis with respect to link 3 moving parts between horizontal to vertical orientations. This allows the link 4 to revolve about its own axis in the counter clockwise direction in the first half cycle of motion of robot arm and in the clockwise direction in the return half cycle of motion of robot arm.

Axis 6

This axis allows the link 5 of the robot arm to tilt up and down. This is the relative motion of link 5 with respect to link 4. During the first half cycle of motion of robot arm the link 5 is rotate in the clockwise direction along the axis of joint of link 5 and the link 4 and during the next return half cycle it rotates in the counter clockwise direction along the same axis of joint. This axis is responsible for the pitch and yaw motion. The pitch, or bend, motion is up and down, much like opening and closing a box lid. Yaw moves left and right, like a door on hinges.

Axis 7

This axis allows the gripper of the robot arm to move forward and backward. This is the relative motion of gripper with respect to link 5. During the first half cycle of motion of robot arm the gripper moves in the forward direction along the axis of joint of gripper and the link 5 and during the next return half cycle it moves in the backward direction along the same axis of joint.

Axis 8

This axis again allows the gripper of the robot arm to revolve about its own axis. This is the relative motion of gripper with respect to link 5. During the first half cycle of motion of robot arm the gripper revolves in the counter clockwise direction along the axis of joint of gripper and the link 5 and during the next return half cycle it revolves in the clockwise direction along the same axis of joint. It is responsible for a twisting motion, allowing it to rotate freely in a circular motion, both to position end effectors and to manipulate parts.

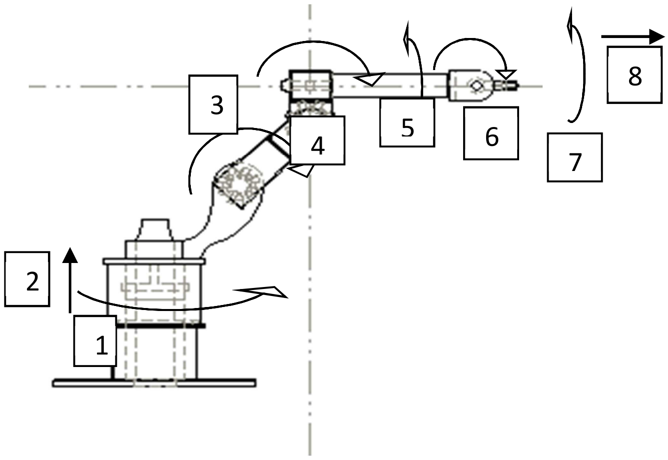

Fig 2 Motions of Robot Arm

7. Static Structural Analysis

Static is the study of structures at a fixed point in time and dynamics is the study of structures over a period of time. Basically statics studies things that don’t move, while dynamics studies things that do. Statics is concerned with moments, forces, stresses, torque, pressure, etc. Dynamics is concerned with displacement, velocity, acceleration, momentum, etc. Statics is concerned about how a mechanical system would act if everything is perfectly motionless and rigid.

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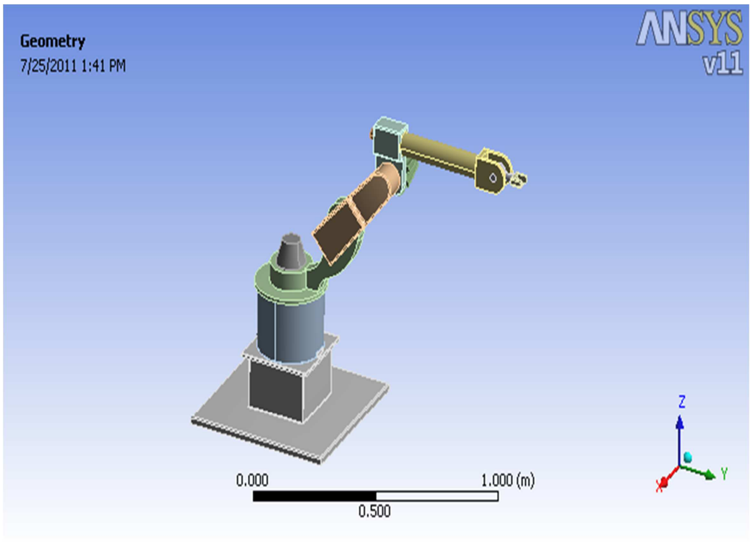

Fig 3 Geometry of robot arm

7.1 Meshing

The process of representing a physical domain with finite elements is referred to as meshing, and the resulting set of elements is known as the finite element mesh. The contact regions between parts were fully defined by faces with bonded type definition. The resulted model includes over 21016 elements and 42798 nodes with a total mass of 353 Kg approximately and a volume of approximately .044938 m^3. The model was considered as appropriate in order to obtain reliable results.

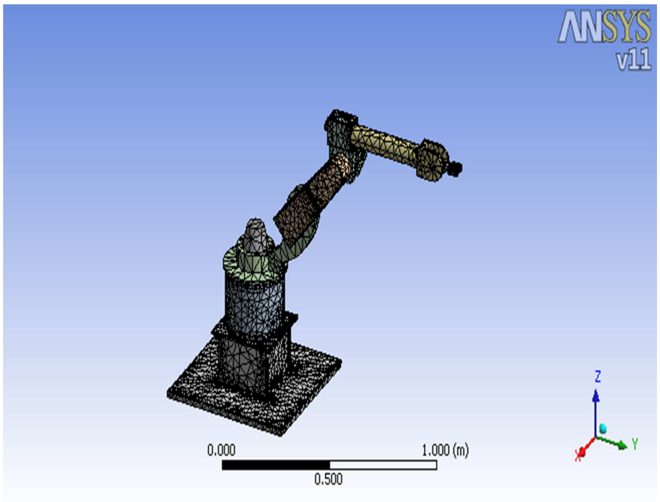

Fig. 4 Meshing of Robot Arm Assembly

7.2 Loads and Input Data

For the input data and loading scheme, the gravitational and inertial forces were introduced in the current model with the maximum values required by the application. The base is fixed. The rotational velocity of 16 rad/sec is applied at the joint between the link 4 and the link 5. The loads were applied at the end point of the gripper. Velocity for the linear motion is 1.0 cm/sec and for the angular motions it is 10 deg/sec. A normal temperature distribution of 22° C was considered and it was assumed that no other conditions influence the environment.

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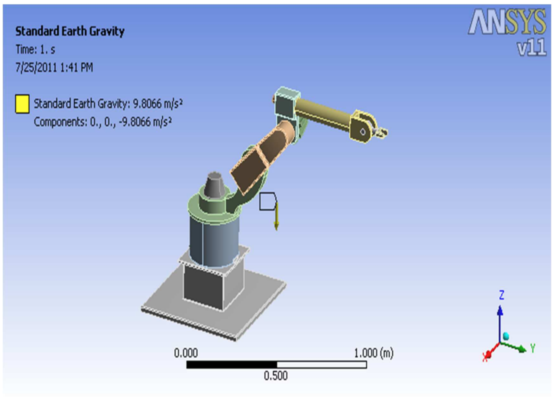

Fig 5 Standard Earth Gravity

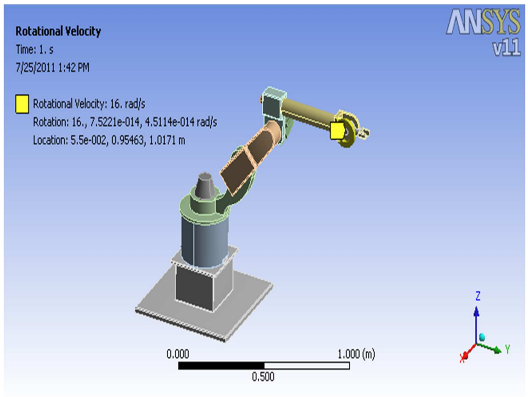

Fig 6 Rotational Velocity

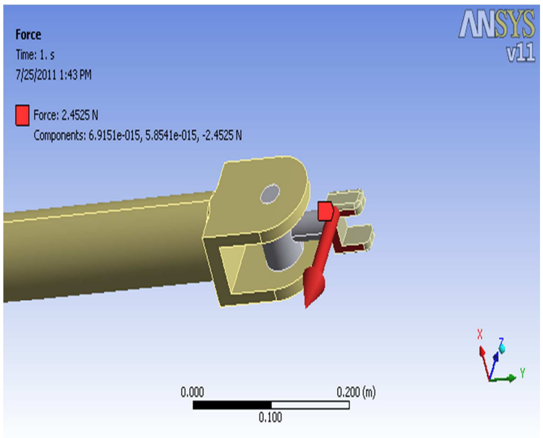

Fig 7 Payload

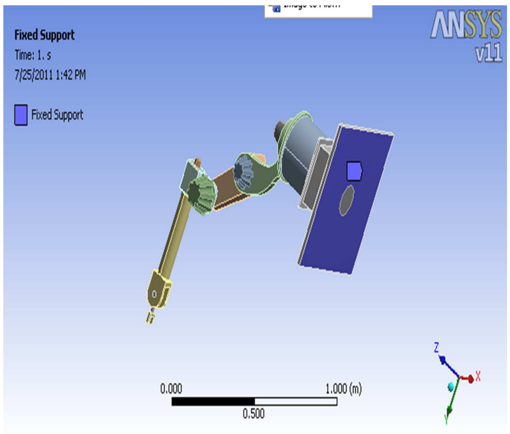

Fig 8 Fixed Support

7.3 Mathematical Approach

Element connectivity Table

Element	Nodes			
	1	2	3	4
1	1	2	3	4

Node Co-ordinate Table

Nodes	X	Y	Z
1	x1	y1	z1
2	x2	y2	z2
3	x3	y3	z3
4	x4	y4	z4

For three dimensional finite element method

Jacobian matrix "J" is given by

$$J = \begin{vmatrix} x14 & y14 & z14 \\ x24 & y\ 24 & z24 \\ x34 & y34 & z34 \end{vmatrix}$$

Where

$$x14 = x4 - x1 \qquad y14 = y4 - y1 \qquad z14 = z4 - z1$$
$$x24 = x4 - x2 \qquad y24 = y4 - y2 \qquad z24 = z4 - z2$$
$$x34 = x4 - x3 \qquad y34 = y4 - y3 \qquad z34 = z4 - z3$$

Let A is the inverse of Jecobian Matrix

$$A = J^{-1} = \frac{1}{\det J} \begin{vmatrix} y24z34 - y34z24 & y34z14 - y14z34 & y14z24 - y24z14 \\ z24x34 - z34x24 & z34x14 - z14x34 & z14x24 - z24x14 \\ x24y34 - x34y24 & xy34y14 - x14y34 & x14y24 - x24y14 \end{vmatrix}$$

Where

$$\det J = x14\,(y24z34 - y34z24) + y14\,(z24x34 - z34x24) + z14\,(x24y34 - x34y24)$$

Strain displacement Matrix is given by

$$B = \begin{vmatrix} A11 & 0 & 0 & A12 & 0 & 0 & A13 & 0 & 0 & -\tilde{A}1 & 0 & 0 \\ 0 & A21 & 0 & 0 & A22 & 0 & 0 & A23 & 0 & 0 & -\tilde{A}2 & 0 \\ 0 & 0 & A31 & 0 & 0 & A32 & 0 & 0 & A33 & 0 & 0 & -\tilde{A}3 \\ 0 & A31 & A21 & 0 & A32 & A22 & 0 & A33 & A23 & 0 & -\tilde{A}3 & -\tilde{A}2 \\ A31 & 0 & A11 & A32 & 0 & A12 & A33 & 0 & A13 & -\tilde{A}3 & 0 & -\tilde{A}1 \\ A21 & A11 & 0 & A22 & A12 & 0 & A23 & A13 & 0 & -\tilde{A}2 & -\tilde{A}1 & 0 \end{vmatrix}$$

Here

$\tilde{A}1 = A11 + A12 + A13$

$\tilde{A}2 = A21 + A22 + A23$

$\tilde{A}3 = A31 + A32 + A33$

Stress Strain Relation Matrix

$$D = \frac{E}{(1+\upsilon)(1-2\upsilon)} \begin{vmatrix} 1-\upsilon & \upsilon & \upsilon & 0 & 0 & 0 \\ \upsilon & 1-\upsilon & \upsilon & 0 & 0 & 0 \\ \upsilon & \upsilon & 1-\upsilon & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.5-\upsilon & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.5-\upsilon & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.5-\upsilon \end{vmatrix}$$

Volume of the element

$$V_e = 1/6 \; |\det J|$$

Element stiffness matrix

$$k^e = V_e B^T DB$$

Now, $KQ = F$

Where

K – Global Stiffness Matrix

Q – Displacement

F – Force

Stress is given by

$$\sigma = DBq$$

7.4 Analysis of Robot Arm

Analysis of the robot arm was analyzed using dedicated software for FEM analysis. The model was exported to FEM processor i.e. in ANSYS, the geometry was updated and the structure meshed using 3D elements. Considering the load and input mentioned previously, a static analysis was carried out for the entire system, in order to obtain the main parameters of deformation, stress & fatigue. In considering static force analysis of a robot arm, all joints are first locked so that the arm becomes a structure**.**

The static analysis comprises an assessment of the total deformation, equivalent (von Mises) stress under the loads mentioned above, max shear stress and the fatigue tool i.e. for life and damage and safety factor. An analysis of non-operational robot was done only considering the gravitational forces. The inertial forces were introduced as well, to show a complete static analysis of the operational robot.

The static analysis concludes with results at the below cases of 250 Gms, 500 Gms, 5 Kg, 15 Kg and 25 Kg. The regions exposed to the highest stress can be observed.

Table 1 Results of Static Analysis

Load		Deformation (mm)	Equivalent (Von Mises Stress) MPa	Max Shear Stress MPa	Life (Cycles)	Damage	Safety Factor	Frictional Stress MPa	Penetration (mm)
5 Kg	Min	0	$423.76X10^{-6}$	$237.5 X 10^{-6}$	$1X10^{6}$	1000	1.1574	0	0
	Max	0.21959	74.476	38.936	$1X10^{6}$	1000	15	138.55	$4.1559 X10^{-5}$
15Kg	Min	0	$567.8X10^{-6}$	$299 X 10^{-6}$.	$1X10^{6}$	1000	1.1956	0	0
	Max	0.18588	72.098	37.687	$1X10^{6}$	1000	15	136.47	$3.9871 X10^{-5}$
25Kg	Min	0	$522.24X10^{-6}$	$275.27 X 10^{-6}$	$1X10^{6}$	1000	1.2364	0	0
	Max	0.16108	69.719	36.439	$1X10^{6}$	1000	15	135.72	$3.8182 X10^{-5}$

8. Conclusion

In this paper the model analysis of eight degrees of freedom robot arm is carried out. This concept is generated for the better assessment of part by using a single robot arm in the industrial applications such as arc welding, spot welding, spray painting, assembly line and many more. There are total eight degrees of freedom in the robot arm, out of which three are revolving motions, three are rotary motions and two are reciprocating motions. All the motions are successfully completed.

The results are analyzed for static analysis, the minimum total deformation for all the cases are zero and is at the base where as the maximum total deformation is mostly in the upper part of robot arm where load is applied for all the cases i.e. link 5 & gripper and these maximum total deformation is very less which is also negligible

From the study it is concluded that this robot arm allow a wide range of arm positions for any given target position, thus giving a great flexibility of motion than six-degree of freedom systems, which have only a finite number of solutions for a target position.

The current work continues while further work should be focused to check the results of the present study and find a solution to improve the results, experimental research suggested for the analyzed model in order to validate the virtual model used.

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