

REDUCING LEAD TIME FOR MODELING IN CAD SIMULATION SOFTWARES

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ABSTRACT

Flexible components, such as rubber hoses, are subject to large elastic deformations during movement of the rigid components to which they are attached. Currently, there is no inherent capability in any solid modeling software to accurately depict the shape of the hose between any two attachment points. Keil (2001) made the hose model in ADAMS/View simulation software. Keil (2002) stated that it is a very time consuming and cumbersome process to set up the model with the flexible beams and its associated joints for modeling of a flexible body without any user errors. This paper presents a method to automatically build a flexible element model using the principles of spatial orientation and vector mathematics. These accurate mathematical principles would maintain the precision in the flexible element model as suggested by Keil while reducing the time for building a hose model to minutes from hours.

1 INTRODUCTION

The Society of Automotive Engineers (SAE) Handbook gives many specifications for the design and connection of rubber hoses. The document has identified some preventive measures, which were based on practice rather than on a rigorous analytical procedure.

Keil (2001) made the hose model in ADAMS/View simulation software using its ability to model flexible beams and orient the translational, revolute and fixed joints. The feature of ADAMS/View used to create the hose is the "discrete flexible link" function. This function creates the flexible massless beams between the user-defined cylinders.

Keil (2002) noted that it is imperative to be very precise regarding the orientation and attachment points of the hoses. He stated that it is a very time consuming and cumbersome process to set up the model with the flexible beams and its associated joints for modeling of a flexible body without any user errors.

1.1 Principles Relevant to the Definition of Geometric Entities in the Model

The automatic generation of the flexible body model in simulation software involved the following steps:

1. Extracting the location of attachment points
2. Establishing a mounting convention
3. Specification of orientation of the geometric entities

1.2 Extracting of Mount Point Data

The Initial Graphics Exchange Specification (IGES) format is a text file, which incorporates the data of the geometric entities in the CAD file. The format of the IGES file is very structured, with certain standards for each geometric entity. The spacing between the numeric and alphabetic fields in the IGES file is crucial. There are 81 fields in a line of the IGES text file, and the spacing has to be honored so that it can be read and interpreted by the different CAD softwares for drawing of the entities with their associated data.

The entity type number for a point is 116. The user makes four points (for example A, B, C and D) in CAD. A sample IGES file with the location of the four points is given in Appendix A. The C++ program searches for the location of the points in the IGES file in the midst of innumerable other entities and extracts the numerical values of the x, y and z coordinates of the points and stores them in an array.

1.3 Establishing a Mounting Convention

The attachment points of the flexible element could be any pair of points among A, B, C and D as shown in Figure 1. The vector direction is important for the desired flexible element path as per the requirement of the designer. A change in the vector direction at the attachment points at

either end can result in different geometries as shown in Appendix B. As an example, the hose is made in the vector direction from A to B and D to C as shown in Figure 1. In this case B and D are the attachment points. It is essential that there be no other entities that are named A, B, C and D in the CAD file.

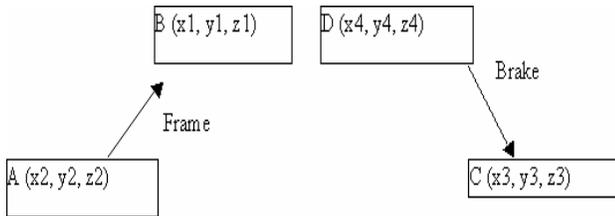


Figure 1: Vector directions at the attachment points

2 ROTATION ANGLES FOR GLOBAL ORIENTATION

The end connectors can be modeled as the cylinders from A to B and D to C, in simulation software using a combination of vector mathematics and rotation of bodies. A brief review of the rotation of bodies in space in the global coordinate system and the computation of their orientation served as the foundation in the determination of the orientations of the entities necessary for the generation of the flexible element model.

The true rotation of a body about a vector in space is performed around it by having a line of sight along the vector. However, it is necessary to know the true length of the line in order to determine its point view. The computation of the various angles keeping in view these concepts are given below. The vector is brought in line with the global z-axis and then the rotation of the body in space (for example θ_3) is made around the point view of the vector. The representation of a vector in space is $ax + by + cz$, where a, b and c are the coordinates of the vector on the x, y and z axes respectively. The first rotation is made around the global z-axis by an angle (θ_1) given by the equation:

$$\tan\theta_1 = \frac{b}{a} \tag{1}$$

A rotation by this angle would get the vector in the X-Z plane. The rotation by the next angle (θ_2) around the global Y-axis would bring the vector in line with the global Z-axis. The length of a vector whose one end is the origin, as in this case, is given by:

$$\sqrt{(a^2 + b^2 + c^2)} \tag{2}$$

This is also the length of the hypotenuse. Because the true length of the adjacent side is c, therefore, by the Pythagorean theorem, the opposite side is

$$\sqrt{(a^2 + b^2)} \tag{3}$$

Hence, the second angle of rotation about the global Y-axis is given by:

$$\tan\theta_2 = \frac{\sqrt{(a^2 + b^2)}}{c} \tag{4}$$

Now, since the true length of the line is along global z-axis, the point view of the line is known, with the line of sight being along the global z-axis. The true rotation (θ_3) can now be made about this vector, and then the body is placed back into the space along with the vector. This is accomplished by having a reverse order rotation to the vector through the angles $-\theta_2$ and $-\theta_1$. The negative sign denotes the opposite direction of rotation according to the right hand rule. Hence the vector is back in its original place with the body, however rotated through the angle (θ_3) around the vector .

The Z-X-Z body rotation sequence was used for orientation of geometric entities in space. This means that the first rotation is given around the local Z-axis, then the local X-axis, and finally, once again around the local Z-axis of the body. If the Z-axis of a geometrical entity (for example a cylinder) is initially aligned with the global Z-axis, then a vector AB can be assumed to lie along the Z-axis of the body. The rotations are given in order to orient the vector in the final position as in reality. The angles for the Z-X-Z global rotations could be found by using the computations described previously. In this case, the z-axis of the cylinder had to be aligned with the global z-axis through a rotation around the global z-axis, then around the global x-axis, and finally, around the global z-axis. The last rotation around the global z-axis was 0^0 as the previous two rotations were enough to line up z-axis of the cylinder with the global z-axis.

The first rotation had to bring the vector AB ($ax + by + cz$) to the YZ plane. The angle (θ_1) through which it had to be rotated is:

$$\tan\theta_1 = \frac{a}{b} \tag{5}$$

The next rotation around the global x-axis, which brings the vector AB in line with the global z-axis is:

$$\tan\theta_2 = \frac{\sqrt{(a^2 + b^2)}}{c} \tag{6}$$

3 SPECIFICATION OF ORIENTATION OF GEOMETRIC ENTITIES OF THE FLEXIBLE ELEMENT MODEL

The global rotations for orienting the cylinders in space could be found by the above equations. However, the relationship between the Z-X-Z-body transformation and the Z-X-Z global rotations had to be found for specifying the orientation of the entities of the model. A Z-X-Z-body orientation of ϕ_1 , ϕ_2 , and ϕ_3 angles indicates that ϕ_1 is the value of the first angle to be rotated around the body z-axis, ϕ_2 the second for rotation around the body x-axis, and ϕ_3 the last angle of rotation around the body z-axis. These three rotations specify the placement of the entities belonging to a geometrical entity in space in the flexible element model. The angles for aligning the axis of the cylinder with the global z-axis are θ_1 , θ_2 and 0^0 as per the equations 5 and 6. The rotation angles for the orientation of the cylinder in the global coordinates are $-\theta_1$, $-\theta_2$, and 0^0 , which means that the reverse rotations would put the cylinder back in space. Here the cylinder, which is assumed to be initially lying along the global z-axis, would be first rotated by 0^0 about the global z-axis, then by $-\theta_2$ about the global x-axis and finally, by $-\theta_1$ about the global z-axis for placing the cylinder in its appropriate position. The relationship between the Z-X-Z global orientation and Z-X-Z body orientation was found to be $\phi_1 = 180 + (-\theta_1)$, $\phi_2 = -(-\theta_2)$, $\phi_3 = 180 + (0)$. For example, a cylindrical rod with Z-X-Z body rotations of $111.8014^0, 79.84^0, 180^0$ (Rod A) and the other one with Z-X-Z global rotations of $-68.1985^0, -79.48^0, 0^0$ (Rod B) was found to have the same final position as shown in Figures 2 through 7.

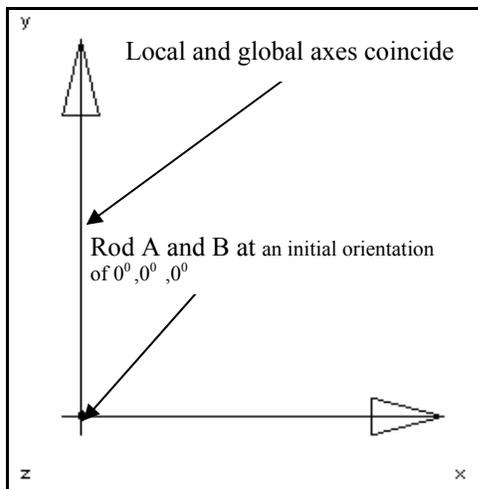


Figure 2: Front view of rods A and B in the initial position

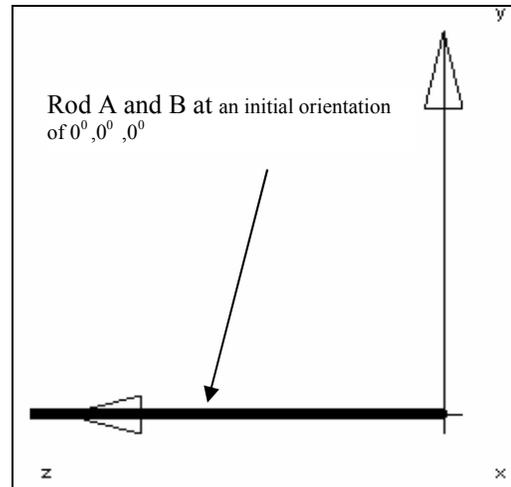


Figure 3: Side view of rods A and B in the initial position

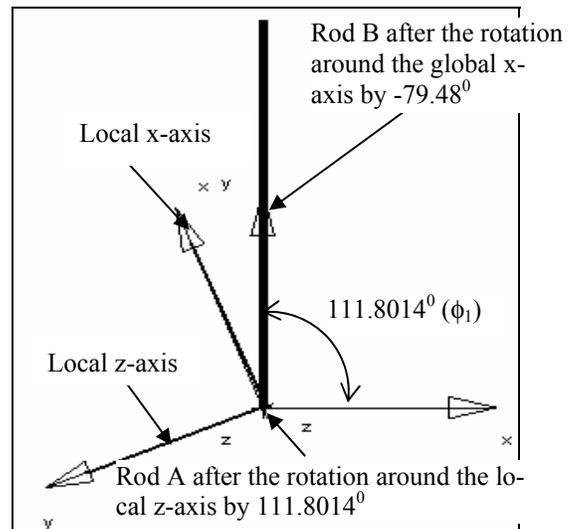


Figure 4: Front view of Rods A and B after the first rotations of ϕ_1 and $-\theta_2$ respectively

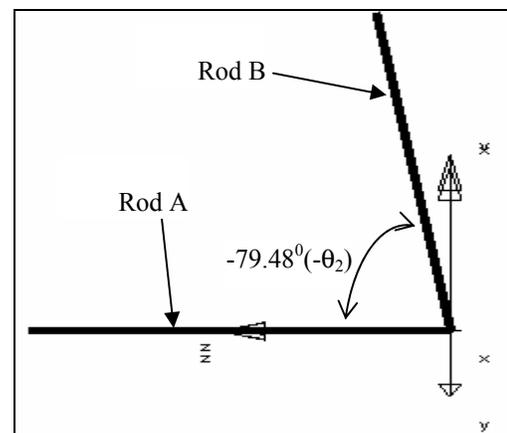


Figure 5: Side view of rods A and B after the first rotations of ϕ_1 and $-\theta_2$ respectively

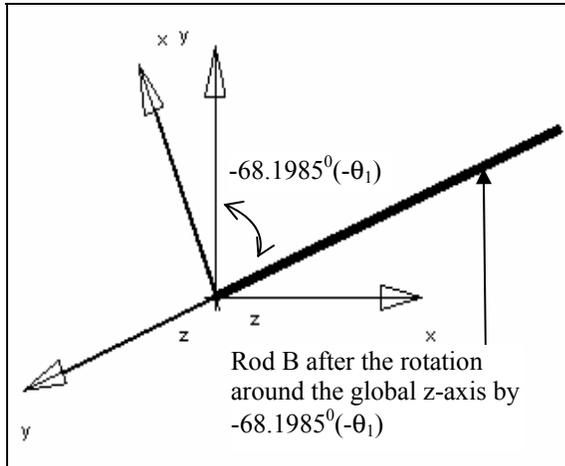


Figure 6: Front view of the final position of rod B after second rotations of $-\theta_1$

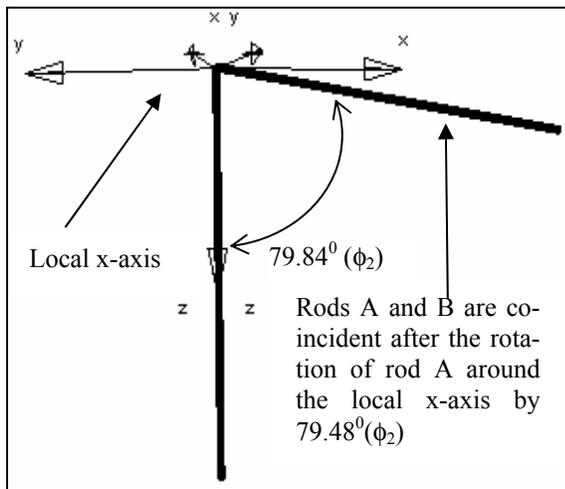


Figure 7: Top view showing rod A at the same final position as rod B after the second rotation of rod A by ϕ_2 around the local x-axis

There are some cylinders in the simulation model that have their z-axis aligned with the global x-axis. The equations for the values of the rotation angles for aligning the z-axis of the cylinder with the global x-axis are different from equations 5 and 6. In this case, the z-axis of the cylinder has to be aligned with the global x-axis through the first rotation around the global z-axis; (this rotation is 0^0 as the next two rotations are enough to line up the z-axis of the cylinder with the global x-axis), then the global x-axis, and again around the global z-axis in keeping with the Z-X-Z global rotations. The second rotation about the x-axis has to bring the vector AB to the XY plane. The angle (θ_1) through which it has to be rotated is given by the equation:

$$\tan\theta_1 = \frac{c}{b}. \tag{7}$$

The next rotation around the global z-axis, which brings the vector in line with the global x-axis, is given by the equation:

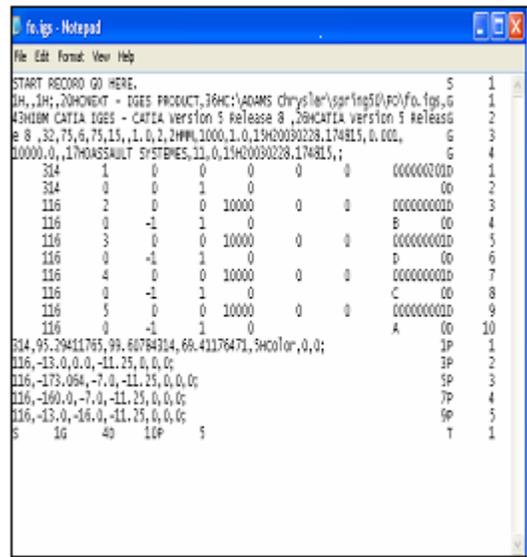
$$\tan\theta_2 = \frac{\sqrt{(b^2 + c^2)}}{a}. \tag{8}$$

A C++ program was used to write the text file containing the global locations and orientations of the geometry of the flexible element model. The length of flexible body and angle by which it is to be twisted is specified by the user in the GUI dialogue box of the program.

The values of the x, y and z coordinate of the center of mass locations of the twisted flexible body were captured by a second C++ program. The C++ program also wrote the iges text file, which would make points at each of the center of mass locations, make lines (polyline curve) between adjacent points and define a plane normal to the curve.

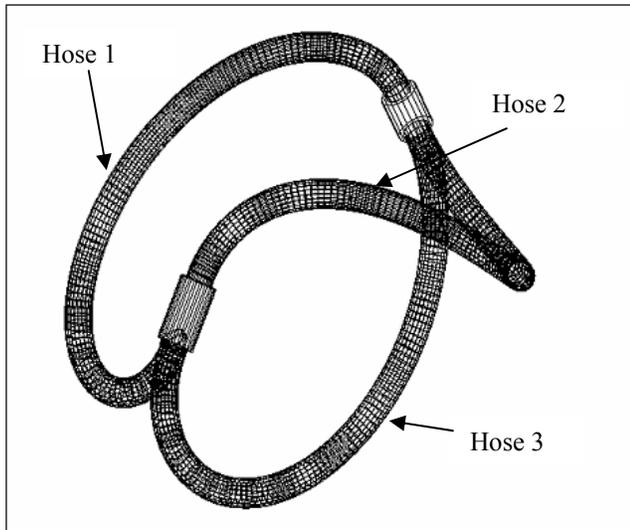
Once the base model in simulation software has been generated it can be viewed in CAD by importing the IGES file.

APPENDIX A: SAMPLE IGES FILE WITH THE LOCATION OF THE FOUR POINTS A,B,C,D



**APPENDIX B: DIFFERENT HOSE GEOMETRIES
DEPENDING ON VECTOR
DIRECTIONS AT THE
ATTACHMENT POINTS**

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