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Computer-Aided Modeling and Manufacturing of Spherical Mechanisms via a Novel Web Tool

In this paper, we present a novel web-based computer-aided modeling and manufacturing software tool for spherical mechanisms. Our purpose is to facilitate the analysis, dynamic simulation, and manufacture of one degree of freedom spherical four-bar mechanisms. First, a brief review of some of the current computer-aided design software for spherical four-bar mechanisms is presented. These software packages provide the three-dimensional visualization and computational capabilities necessary to synthesize and analyze spherical four-bar mechanisms. However, to date, no readily available and effective tools exist to aid in the modeling and manufacture of spherical mechanisms. Next, the kinematics of spherical four-bar mechanisms are reviewed as they pertain to their geometric modeling and manufacture. Finally, we present our web-based implementation of a computer-aided modeling, simulation, and manufacturing methodology for spherical four-bar mechanisms called SFBDESIGNER *(for spherical four-bar designer).* SFBDESIGNER *facilitates the design, dynamic simulation, prototyping, and manufacture of spherical four-bar mechanisms.* [DOI: 10.1115/1.2795307]

Introduction

SFBDESIGNER is a novel computer-aided manufacturing (CAM) software for spherical four-bar mechanisms. These devices have proven to be useful for orienting parts; however, their manufacture can be challenging. To date, this challenge has limited their use in industrial and consumer applications. SFBDESIGNER was created to address this challenge and facilitate the design and use of spherical mechanisms. SFBDESIGNER provides designers a free, web-based tool to layout the parts and view the assembled mechanism. SFBDESIGNER lets the user specify the dimensions of a spherical mechanism and then part and assembly drawings are automatically generated. These geometric models and drawings can be downloaded in STEP, dxf, iges, PROENGINEER part and assembly files, and other formats for use with other CAD/CAM software packages. Moreover, tiff and jpg images of the assembled mechanism can be generated as well. These files can be used to visualize the three-dimensional assembly of the mechanism (ASM, JPG, or TIF), perform static and dynamic analyses (ASM), make a rapid prototype (STL or STEP), or finally to manufacture the mechanism using a computer numerically controlled (CNC) machine tool (IGES or DXF). SFBDESIGNER facilitates the design, visualization, prototyping, and manufacture of spherical four-bar mechanisms.

SFBDESIGNER lays out the mechanism's links using circular arcs with feet at either end. The feet are designed to facilitate the accurate placement and orientation of the axes and the use of bearings. The circular arcs are designed to allow the links to be spaced closely together. The result is a compact mechanism that conserves material and has been layed out to facilitate precise arclengths and accurate axis placement.

Traditional one degree of freedom four-bar linkages are capable of generating only planar movements. Spherical four-bar mechanisms produce motion that is constrained to the surface of a sphere while still only having one degree of freedom, see Fig. 2. This complex motion is desirable since the mechanism can be designed to move a body through many orientations while still being driven by a single motor. It is often stated that spherical mechanisms are challenging to design, visualize, prototype, and manufacture. The synthesis, analysis, design, and visualization problems have been solved to some extent by the CAD programs such as SYNTHETICA [1], SPHINX [2], SPHINX-PC [3], ISIS [4,5], and OSIRIS [6–8]. Even though these packages facilitate the synthesis and analysis of spherical mechanisms, they do not assist the important subsequent stages of prototyping, testing, and fabrication [9]. As stated by Laliberté [10] "…the design and fabrication of a prototype using traditional techniques is rather long, tedious, and costly." The manufacturing methodology proposed here facilitates the prototyping and manufacturing of spherical mechanisms. The challenges of manufacturing spherical four-bar mechanisms that the methodology address are precise link arclengths, precise radial link placement, accurate orientation of axes, compactness of the mechanism, and a complete and consistent solid geometry model.

The methodology presented here yields accurate axis location for the links and lays out the mechanism with compact circular arcs. Precise axis placement is vital to the manufacturing of spherical mechanisms since inaccuracies may result in the link not rotating at the proper radius, which may in turn lead to increased friction and/or binding of the mechanism. Circular arcs are used because they yield a compact mechanism and when machined permit the links to be spaced closely together, which reduces internal loading and conserves material.

It is often stated that once a mechanism has been designed, it is desirable to construct a fully functioning prototype [11,12]. The web-based methodology presented here can be used to (1) layout the final design of a mechanism, (2) this layout may then be used to quickly manufacture a fully functioning physical prototype, or (3) the assembly and part files may be used to generate a virtual prototype of the device. SFBDESIGNER is an implementation of this methodology that utilizes PROENGINEER WILDFIRE 2.0 and ASP.NET to provide a free online tool for the design of one degree of freedom spherical part orienting devices. However, it is important to note that SFBDESIGNER provides the designer with industry standard file formats (dxf, step, iges, stl, etc.) and therefore it is useful

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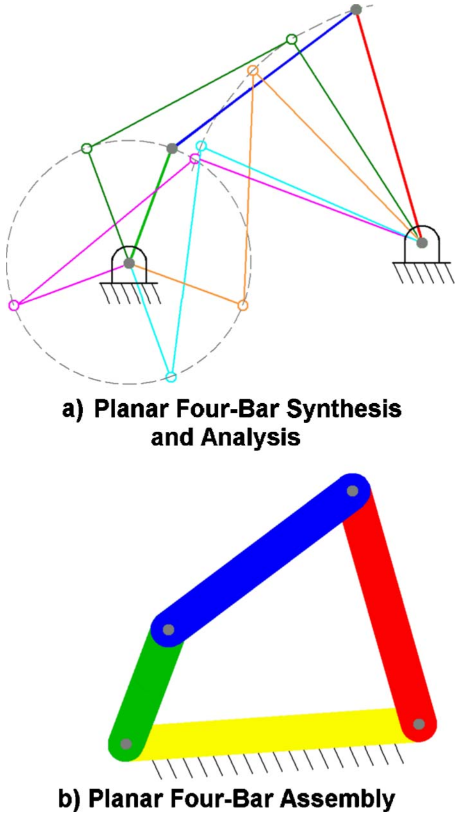

Fig. 1 Planar mechanism design

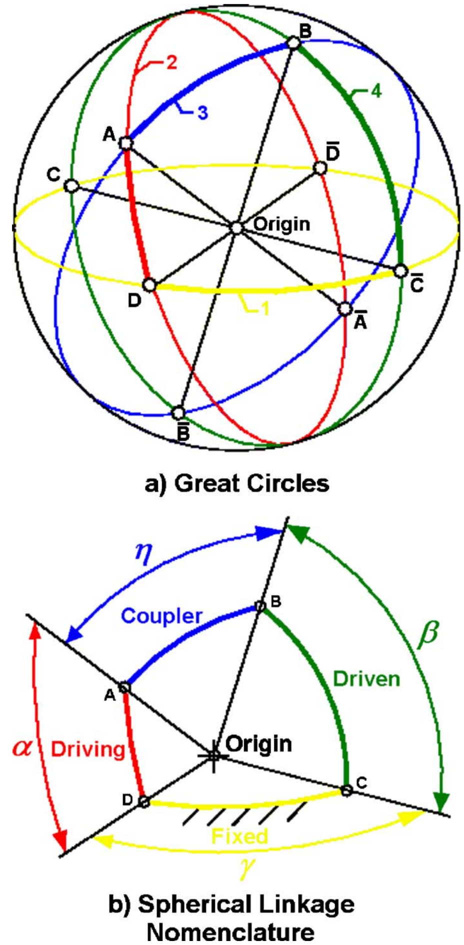

Fig. 2 Spherical mechanism design

to all designers regardless of their brand of CAD software. The output files from SFBDESIGNER can be used for 3D printing or loaded into CNC machining centers for manufacturing. Moreover, SFBDESIGNER also provides designers with a three-dimensional rendered image of their assembled design (tiff, jpg). Using these automated and accurate tools facilitates the manufacturing and simulation of spherical mechanisms with tight machining tolerances on the critical dimensions (e.g., link arclength, axis placement, and orientation).

Related web-based tools for mechanism synthesis, analysis, or design include the following. A web-based tool for planar mechanisms was presented in Ref. [13]. In 2002, Yin [14] discussed a web-based software for spatial CAM design and in 2000, Larson and Cheng [15] presented a web-based planar CAM-follower system design tool. A related work addressing the manufacture of spherical CAM mechanisms appears in Ref. [16]. Turner et al. [17] discuss the manufacture of spherical mechanisms to build multiple designs with simple part geometries and manufacturing processes.

This paper begins with a review of the geometry and kinematics of spherical four-bar mechanisms that pertain to their layout and manufacture. Next, the geometric layout of spherical four-bar mechanisms is discussed. This is followed by a detailed presentation of the design and function of the novel web-based software tool. The final section presents a case study demonstrating the utility of SFBDESIGNER.

Spherical Four-Bar Mechanisms

Traditional planar four-bar mechanisms are a one degree of freedom closed kinematic chain connected by four revolute (R) joints. The joint axes are all parallel and the mechanism is modeled in a single plane. A spherical four-bar mechanism is also a one degree of freedom closed kinematic chain connected by four revolute joints. However, for spherical mechanisms, the joint axes all intersect at a common point. This point is the center of the sphere that the mechanism moves about [18]. In both cases, the mechanisms can be designed in two dimensions: on the plane and on the sphere, see Fig. 1(*a*). However, when you need to manufacture and assemble the links of the planar four-bar mechanisms, they can no longer be coplanar. Instead, they must lie in parallel

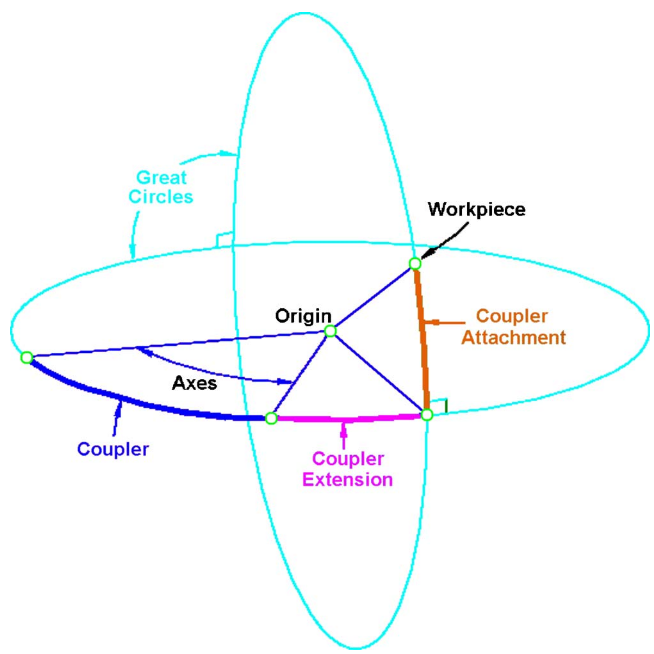

Fig. 3 Attaching the workpiece to the coupler

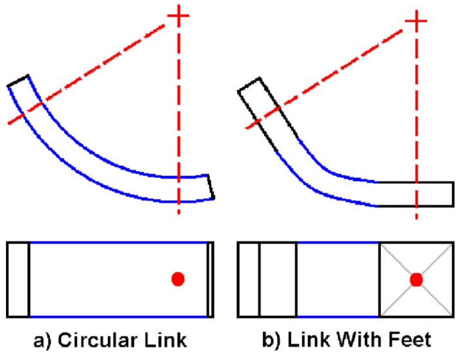

Fig. 4 Link geometry

planes, see Fig. 1(*b*). Similarly, for spherical four-bar mechanisms, the links must be manufactured and assembled to operate in concentric spheres. Manufacturing links to operate in concentric spheres with accurate link lengths and in a compact mechanism are facilitated by the web-based methodology presented here.

In spherical kinematics, a link is characterized by the great circle arc subtended by its two joint axes. The two great circles associated with two adjacent links intersect at two points on the sphere. These two points define a line in space which is the *R*-joint axis that connects the two links. Note that this line passes through the center of the concentric spheres. Figure 2(*a*) shows the intersection of four great circles and the resulting axes of rotation and Fig. 2(*b*) shows the spherical four-bar linkage axes and link nomenclature.

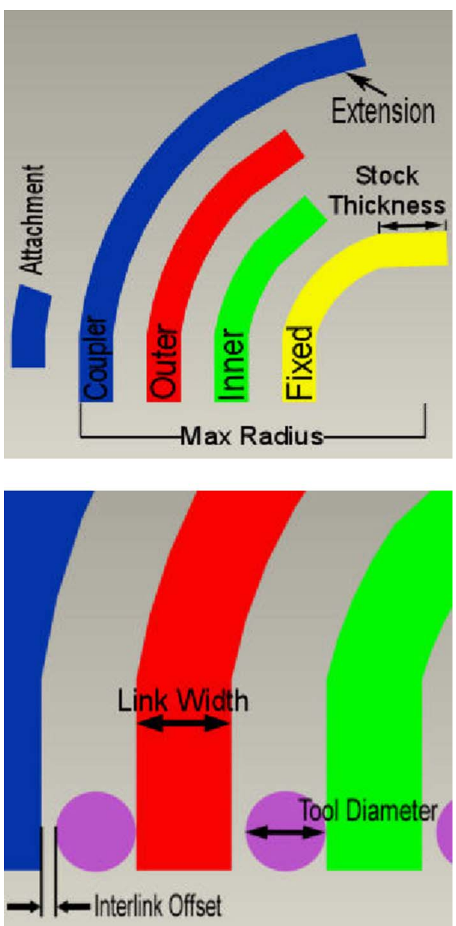

Fig. 5 Radial increment and manufacturing nomenclature

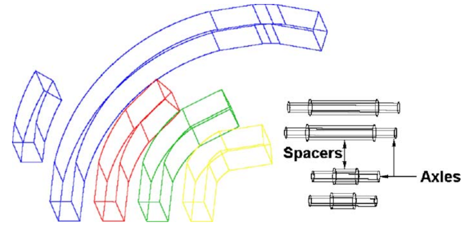

Fig. 6 The sample mechanism-part layout

In spherical four-bar mechanisms, the coupler link performs general spherical motion. Attaching a workpiece or tool to the coupler link usually requires additional parts. Here, spherical mechanisms may require two parts, an extension and an attachment, to attach the workpiece to the coupler. The *coupler extension* is an arclength that lies in the same plane and has the same radius as the coupler, see Fig. 3. The *coupler attachment* is orthogonal to the coupler and it too has the same radius as the coupler. We refer to links that operate at the same radius as being in the same layer. Hence, the coupler, coupler extension, and the coupler attachment are all in the same layer.

Link Geometry

The links of a spherical four-bar mechanism are described by their angular length along great circles, see Fig. 4(*a*). Proper placement of the axes in spherical four-bar mechanisms is vital. If the locations of the axes are not accurate, then the resulting links will not rotate about the center of the concentric spheres. A novel link geometry that will facilitate precise link arclengths, placement of link axes, and compactness of the mechanism is circular arcs with rectangular ends called *feet*. The feet provide a flat surface, the geometric center of which may be easily found, that facilitates the locating and machining of the axes, see Fig. 4(*b*). Moreover, a jig or fixture could be used to assist in locating and machining the axes since all the feet of the mechanism are identical. By incrementing the link radii, the links can be designed to operate on different layers of concentric spheres. This geometry solves the manufacturing and assembly problems of axis location while still keeping the mechanism compact. To complete the design process, the geometry of each link needs to be described. An arclength, radius, foot size, and link width describe each link of the mechanism. The foot size and link width can be considered constant for all the links of the mechanism. The radius of each link can be determined by declaring the radius of the outermost link and then stepping in at increments of link width, cutting tool diameter and offset distance for each subsequent link, see Fig. 5.

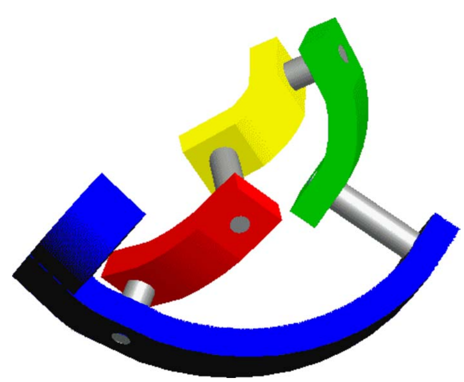

Fig. 7 The assembled sample mechanism solid

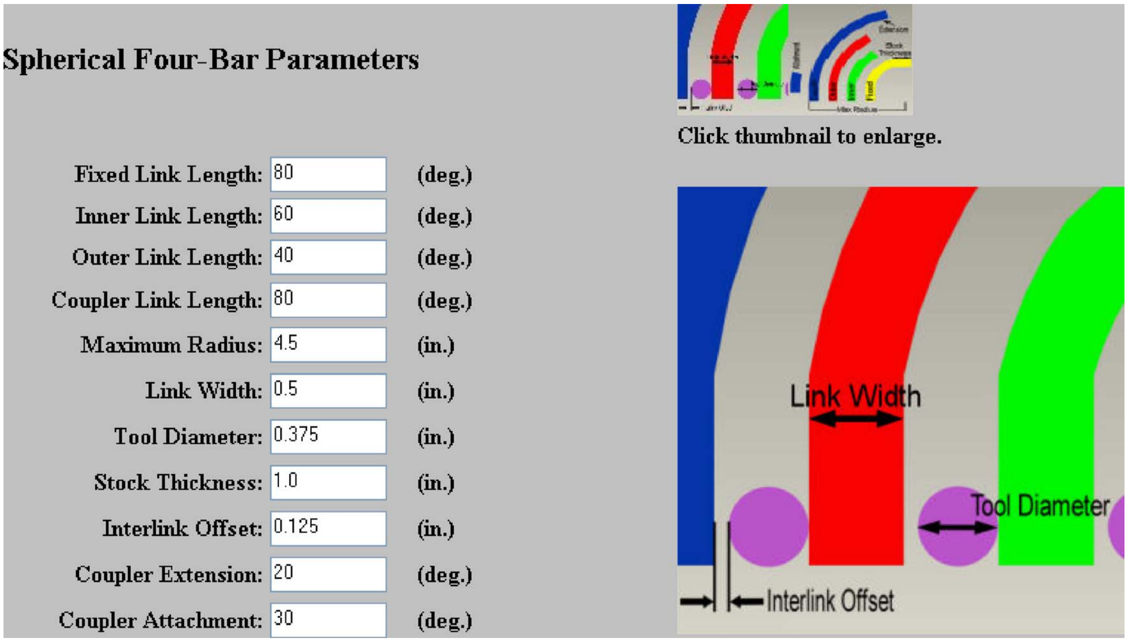

Fig. 8 The SFBDESIGNER parameter interface

The extension and attachment of the coupler have the same radii as the coupler link and move in the same layer as the coupler. This ensures that the extension and attachment do not interfere with adjacent links on neighboring layers.

Coupler Extension. The coupler link has two feet for axial location and manufacture and the link may need to be extended so that the workpiece may be attached to the mechanism. If the coupler has an extension that does not lie completely within the coupler link, another foot or partial foot is added to the link. This additional foot can be used to locate and mount the coupler attachment to the coupler link. In Ref. [19], all of the five possible extension cases are addressed in detail.

Coupler Attachment. The geometry of the coupler attachment link differs from the other links. The base end that attaches to the workpiece has half of a foot. The center of the end of the half foot is the point where the workpiece is attached so that the mechanism produces the desired motion. The other end of the link has no foot. This is because it will be attached to the coupler link. The thickness of the coupler link acts as the foot of the attachment link. There are three different cases that are encountered when laying out the coupler attachment link and they are addressed in detail in Ref. [19].

Assembling the Mechanism. To assemble the drawn mechanism, the links may be connected to form a closed chain as follows. Remember that the links move on layers of concentric spheres so the outer edge of the smaller radius link will always be attached to the inner edge of the larger radius link. The smallest link is attached to the second smallest link with a $Size_1$ spacer being used to maintain distance between the links. The other end of the second smallest link is attached to the largest link using the $Size_2$ spacer. The other end of the coupler link is attached to the second largest link with the $Size_1$ spacer keeping the distance. The chain is closed using the final $Size_2$ spacer to attach the remaining ends of the second largest link and the smallest link together. Spacer sizes are determined by using the methodology presented in Ref. [20]. The parts of a spherical mechanism as layed out by SFBDESIGNER are shown in Fig. 6 and the assembled mechanism is shown in Fig. 7. SFBDESIGNER generated the piece part layout of Fig. 6 as well as the rendered and assembled device shown in Fig. 7.

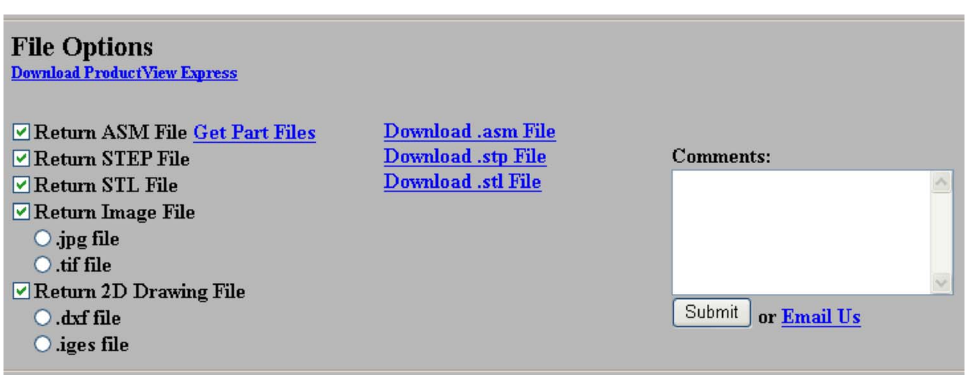

Fig. 9 The SFBDESIGNER output interface

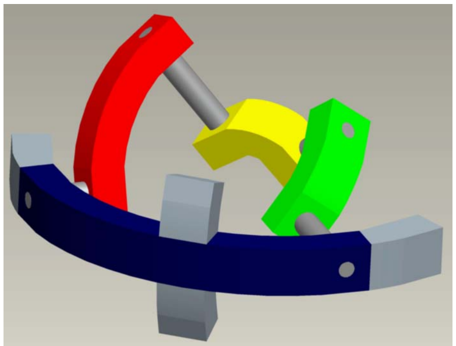

Fig. 10 The fundamental mechanism

SFBDESIGNER

In this section we present the implementation of the above methodology into the novel web-based software tool.

Graphical User Interface. The SFBDESIGNER graphical user interface (GUI) is a web form divided into three sections: user information, mechanism parameters (Fig. 8), and output file options (Fig. 9). The required user information and the four-bar mechanism data are stored in a log file on the server so the user may access their previously created four-bar mechanism. The second part of the GUI is the mechanism parameter section. Here, the user enters the dimensions and parameters for their mechanism. The GUI passes these dimensions onto PROENGINEER to create the particular spherical four-bar geometry. SFBDESIGNER displays default values for a sample crank-rocker mechanism that includes a coupler extension and attachment. If a user enters parameters that do not correspond to a four-bar mechanism that can be assembled, the GUI displays an error message and highlights the parameter(s) to modify. To the right of the parameter input area are illustrations showing the physical definitions of the four-bar parameters. If a user needs more detailed information on the parameter inputs, there is a hyperlink to an online help document.

The output file options allow the user to choose what file format(s) to return. SFBDESIGNER can return a variety of file formats including 3D assemblies (.asm, .stl, and .stp), 2D drawings (.igs and .dxf), and rendered images (.jpg and .tif). Hyperlinks to download the requested files appear in this section once the mechanism has been created. By default, the PROENGINEER assembly file option is selected which returns an.asm file. In order to open the assembly file in PROENGINEER, the user must download the part (.prt) files that make up the assembly. There are individual part files for the links, extensions, attachments, and axles of the four-bar mechanism. A hyperlink next to the.asm file selection downloads a compressed archive that includes the individual part files for the mechanism.

ASP.NET

The programmatic goal of the GUI is to obtain dimensions from the user and then apply those dimensions to a generic parametric model in PROENGINEER. The GUI runs ASP.NET code[1] that handles the overall flow of the four-bar construction process. In addition to GUI functions such as data field validation, ASP.NET provides a way to interact with files on the server and make data driven decisions programmatically. After the user has entered all the required information, SFBDESIGNER uses a series of tests to ensure that the user input defines a valid spherical four-bar mechanism that can be assembled. Once the program has verified the input, it writes the user's parameters to a text file on the server. This text file is then utilized by PROENGINEER to update the controlling di-

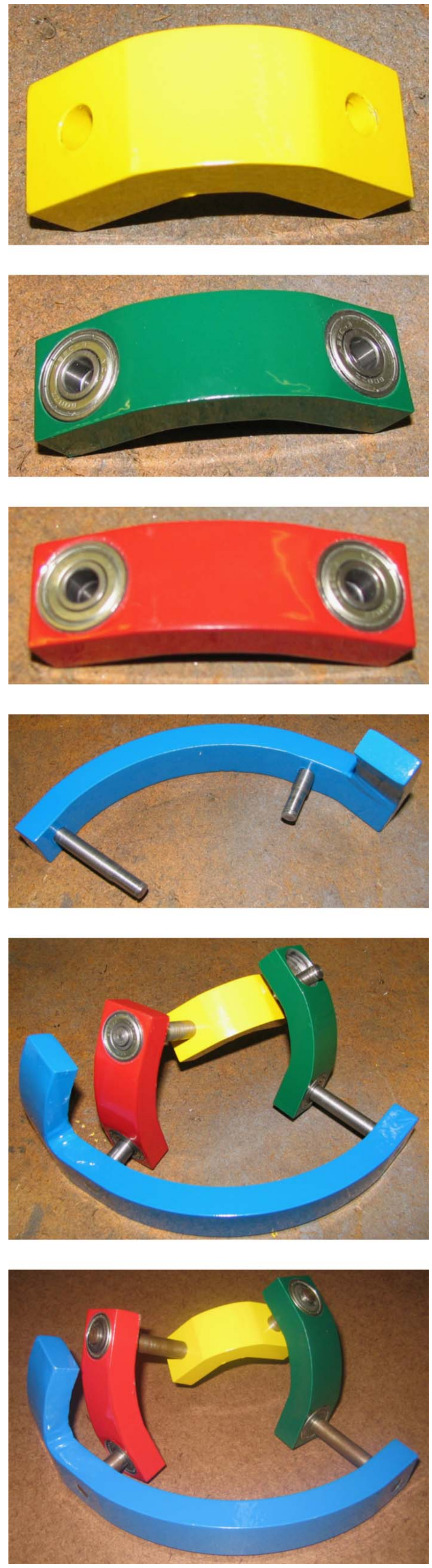

Fig. 11 Manufactured and assembled links

mensions of a generic parametric model. The program then checks what return file options are selected and writes a specific trail file for PROENGINEER with appropriate commands to create the desired

[1]www.asp.net

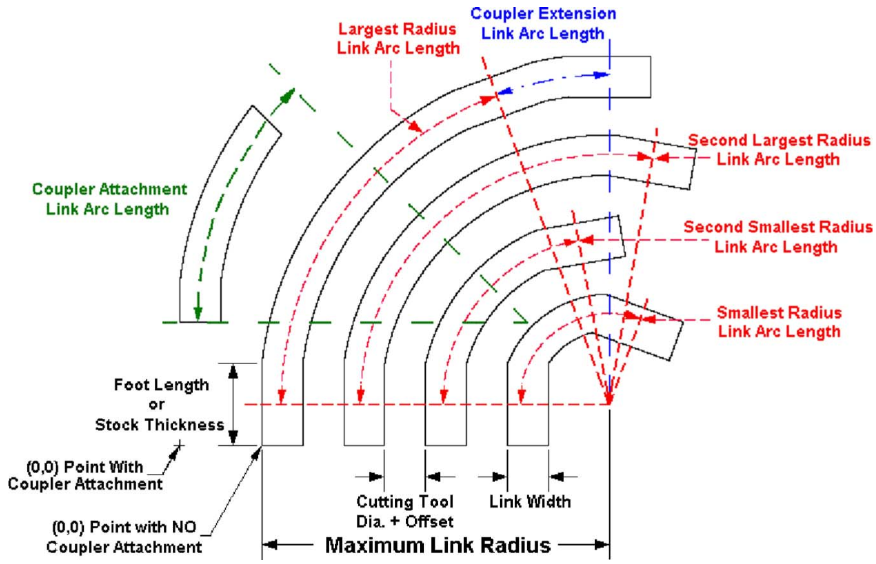

Fig. 12 General layout of links

files. Finally, the program calls a batch file that launches PROENGINEER and runs the newly formed trail file. PROENGINEER takes over control, and the program waits until the files it requested are returned before it posts back links to the user so that they may download their desired files from the server.

PROENGINEER

All CAD modeling for SFBDESIGNER has been done in PTC's PROENGINEER WILDFIRE 2.0.[2] The approach used was to create a generic parametric model of a spherical four-bar mechanism that would be updated dynamically according to dimensions input from a web user. The four-bar mechanism has been assembled as a mechanism in the software allowing the links to rotate so the user can visualize the movement of the assembly. The first step in creating such a model was to design and draw a single spherical link, defined by the flexible parameters. Two types of axles were needed to connect the links, one long and one short. The axles not only act as a revolute joint for the links but also define the spacing between links. SFBDESIGNER also has the ability to include an extension and attachment to the coupler link. To accomplish this, multiple models of extensions and attachments were made to reflect the various geometric differences encountered for specific parameter combinations. All of the parts were modeled with relations attached to the geometry, which allows for flexibility in the dimensions while keeping the design intent intact. Once all the common components had been made, the fundamental four-bar mechanism was assembled using the PROMECHANISM module in PROENGINEER. This type of assembly varies from the standard form, which defines rigid constraints. PROMECHANISM instead defines connections and joints between assembly components. These joints enable the user to drag components of the assembly and visualize the movement of the connected parts. The specific application of this method to a spherical four-bar mechanism means that a user can drag a link of the four-bar mechanism or define a rotation around a revolute joint and see the four-bar mechanism pass through its range of motion. The PROMECHANISM module also provides a way to trace the path of points, show the complete motion envelope, and analyze the kinematics of various parts of the mechanism. Users can take their downloaded assembly file into PROENGINEER and, with minimal previous knowledge, add various types of motors to drive the revolute joints and create an animation of the moving four-bar mechanism. The assembly also makes use of PROENGINEER's flexibility function. Each component of the assembly including the links, spacers, extensions, and attachments has been defined as a flexible part. This simply means that the dimensions of these parts can be modified using parameters and relations within the assembly file. For example, the width of each of the links is defined as a flexible dimension so that a relation can be made equating the link width parameter of the assembly file to the actual width of each link. There are many relations made in the assembly file that link flexible dimensions of the components to parameters of the assembly file. These parameters correspond exactly to the same parameters that are input into the SFBDESIGNER GUI. By defining the parameters in PROENGINEER to be set programmatically, a text file containing all the values can be read in place of a user manually typing each one within the PROENGINEER interface. This assembly file and a second one with the components laid out on a plane are the common models that adjust to meet the specific parameters provided by the user.

Fundamental Mechanism

The fundamental mechanism shown in Fig. 10 contains the links for all possible coupler extension and attachment cases. Each case handles differences in geometry for the extensions/attachments based on their distance from the coupler. The difference in geometry for all the cases resolves any overlap problems that might occur between the extension/attachments and the coupler itself, while simultaneously keeping the links from causing interference problems.

On each end of the coupler, there are four links that correspond to the four possible cases of coupler extension geometry (four on the positive side, four on the negative). In the most general case, the extension is far enough away from the coupler to connect the two parts with concentric arcs, this is Case 1. In Case 2, the extension is closer to the coupler such that the inside edge of the extension overlaps with the coupler; however, the outer edge does not. In this case, the outer edge is connected by an arc as in Case 1 and the inner edge is connected by a line from the end of the coupler to the end of the extension. In Case 3, the extension is even closer to the coupler with both the inner and outer edges overlapping with the end of the coupler. For this case, the overlap is less than $\frac{1}{4}$ of the stock thickness of the mechanism, and therefore lines connect the end of the coupler to the end of the extension for both the inner and outer edges. In the final case for the extensions, the inner and outer edges of the extension overlap

[2]www.ptc.com

Table 1 Infinity fan mechanism data

SPHINX data	
Link/prompt	Angle/value
Largest radii link	88.284 deg
Second largest radii link	53.806 deg
Second smallest radii link	47.350 deg
Smallest radii link	87.894 deg
Link to extend	1
Link extension	−86.350 deg
Link attachment	−46.690 deg
Other data used	
Prompt	Value entered
System of units	1 (U.S. customary)
Stock thickness	1 in.
Cutting tool diameter	0.375 in.
Offset distance	0.125 in.
Link width	0.500 in.
Maximum radius	4.250 in.
SFBDESIGNER output	
Spacer sizes, two of each needed: 0.5 in. and 1.5 in.	

with the coupler by more than $\frac{1}{4}$ of the stock thickness. On the inner edge, a line normal to the end of the coupler connects to the end of the extension and the outer edge is connected as in Case 3. The attachments for the coupler can be placed anywhere along the length of the coupler including any extensions. In the fundamental mechanism, two links on both the top and bottom sides of the coupler are attached to a datum plane that moves them to the proper location on the coupler. The two links correspond to the two cases for attachment geometry. In Case 1, the attachment is far enough away from the coupler such that there is no overlap and it is connected by concentric arcs. In Case 2, the attachment does overlap with the coupler and therefore it is connected by straight lines. For a more detailed presentation of all possible coupler extension and attachment cases, see Ref. [20].

The four primary links of the fundamental mechanism are assembled together in PROENGINEER using the connection tool. The fixed link is the first to be placed in the assembly and is constrained to the origin. Next, the input link is assembled by placing a pin joint between one of its axes and one of the fixed using a flexible dimension for the offset. The output link is then assembled in the same fashion to the other axis of the fixed link. Finally, the coupler is added to the assembly by placing a pin joint between one of its axes and the input link and cylindrical joint between its other axis and the output link. All of the pin joints are defined with flexible dimensions to constrain the offset of the links, and to avoid overconstraining the mechanism, the last joint assembled must be a cylindrical joint. Once assembled in this manner, the four-bar mechanism can then be treated as a mechanism within PROENGINEER.

Dynamic Trail Files. PROENGINEER uses text documents called trail files to keep a record of the menu choices and actions of a user in an active modeling session. The trail files can be opened within PROENGINEER and the archived commands may be executed. These files are generally used for backup purposes; however, here we utilize trail files in combination with ASP.NET to make changes to PROENGINEER files programmatically. The ASP.NET code creates a *dynamic* trail file that is run when PROENGINEER is opened through a batch command. This trail file contains the PROENGINEER commands to open the fundamental spherical four-bar assembly, suppress the appropriate extension/attachments, update the assembly parameters, and save as various file formats all according to the user input. Within the fundamental assembly files, there are multiple coupler extensions and attachments to meet some special cases that might occur in the parameter inputs. However, at most, only one extension and one attachment should appear on the final mechanism. The other extensions/attachments must be suppressed so that they do not cause the regeneration to fail once the user's parameters have been loaded into PROENGINEER. The ASP.NET program as a decision tree finds what extensions/attachments should be suppressed and the appropriate commands are written to the trail file. The trail file can also contain instructions to open, update, and save 2D drawings of the four-bar geometry. Depending on what type of files the user wants returned, the ASP.NET program will write the appropriate commands in the trail file to open the corresponding assembly model. For example, if a user requests a.dxf file, then a command is written in the trail file to open the 2D drawing file with the four-bar components laid out for manufacturing. This method of interacting with PROENGINEER is unconventional; however, it provides an easy and effective solution at no additional cost when compared to purchasing PROINTERLINKLIBRARIES to use in writing C code. Virtually, any process in PROENGINEER can be automated in this form. Simply manually launch the commands in PROENGINEER, examine the automatically generated trail file, and extract the appropriate text. By using a program such as ASP.NET, variables can be defined and linked to user inputs, and these variables can be concatenated into strings to form specific commands that can be run in a PROENGINEER trail file.

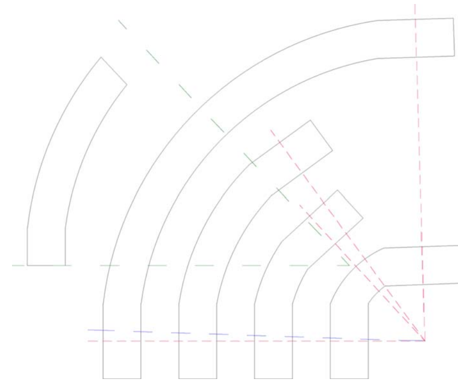

Fig. 13 SFBDESIGNER Infinity fan link layout

Assembling the Mechanism. The piece parts of the sample spherical mechanism as layed out by SFBDESIGNER are shown in Fig. 6 and the assembled mechanism is shown in Fig. 7. SFBDESIGNER generated the piece part layout of Fig. 6 as well as the rendered and assembled device shown in Fig. 7. Moreover, a demonstration sample mechanism was fabricated and color coded, see Fig. 11.

Drawing the Mechanism Links. SFBDESIGNER lays out four or five links with their axial lines, depending on the data entered. If there are four links, they are laid out with one axis of each link

Fig. 14 Infinity fan-top view

lined up along the bottom of the screen. They are arranged, left to right, from largest to smallest radii, with their common center lying to the right. The links' arcs extend clockwise, around the common center. If there are five links, the additional link is the coupler attachment. The first four links are drawn as in the four link case and the fifth link is offset to the left and raised relative to the other links so that as it is extended clockwise, its tool paths will not interfere with the adjacent link, see Fig. 12. It has the same radius as the link that had the coupler extension. The radius of the coupler attachment link may be different from the outermost link, which creates problems for drawing the attachment link without entering the tool path region about the outermost link. In order to avoid this problem, the coupler attachment link is drawn offset to the left at the same spacing as the other links, and is positioned vertically according to which link has been extended and the size of the attachment angle, see Ref. [19].

The general layout of the links, including the coupler attachment case, is shown in Fig. 12. SFBDESIGNER uses colors and line types to show the axial lines of the various links. The axial lines of the regular four links have a common origin and are drawn with dashed red lines. To offset the coupler extension axial line, since it also intersects the common center, SFBDESIGNER uses a different line type that is blue. If there is a coupler attachment, its axial lines are drawn with another line type that is green.

Case Study

SFBDESIGNER has been used to layout the links for the infinity fan, see Ref. [21]. The data for constructing the fan's spherical mechanism were generated with SPHINX, see Table 1, and combined with the desired stock thickness, link width, offset distance, and cutting tool diameter. SFBDESIGNER produced the drawings, see Fig. 13, that were then exported into a CAM package that generated the CNC code to manufacture the links of the mechanism. As seen in Table 1, the coupler extension angle is less than the coupler link angle, placing the attachment within the coupler link. The coupler attachment provided a location to mount the fan at which the desired motion path is followed. The completed infinity fan is shown in Fig. 14.

Conclusions

A novel web-based computer-aided modeling and manufacturing software tool for spherical mechanisms entitled SFBDESIGNER has been presented. SFBDESIGNER uses computer-aided drafting and manufacturing to address many of the challenges encountered when building spherical mechanisms. SFBDESIGNER provides a free, web-based interface to software that generates solid geometric models and an assembly of the mechanism using PROENGINEER WILDFIRE 2.0. However, it is important to note that SFBDESIGNER provides the designer with industry standard file formats (dxf, step, iges, stl, etc.) and therefore it is useful to all designers regardless of their brand of CAD software. The links are designed to facilitate accurate axis placement, which is critical to spherical mechanisms. Moreover, SFBDESIGNER[3] creates compact links, which reduce internal loading and conserve raw materials. Finally, the solid geometry assembly can be used for virtual prototyping and dynamic simulation.

[3]http://my.fit.edu/~pierrel/software.html.

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