animated CAD Solutions for G3AR M3CHAN1SM dES1GN

Embracing new technologies helps place engineers at the center of the gear-design process.

by Sandor J. Baranyi

Two-dimensional and 3D CAD programs have continually lessened the role of the engineer in the actual process of designing gears, gear mechanisms, and mechanisms in general. This unilateral phenomenon can be corrected by using ACADS to increase the designer's interactivity and creativity in that process.

Countless examples of this have been available since April 2003, with the arrival of ACADS as a mechanical design engineering tool.

Gearing and Gearing Profile Types

There are three basic types of contemporary gear profile types:

- involute
- trochoid (cycloid)
- curve-linear

ACADS is suitable to all three profile types, of which the involute is the dominant and best-known to most gear designers. Consequently, it is not necessary to elaborate on the involute in this paragraph of the article.

Trochoidal (cycloidal) gears have enjoyed a slow but persistently increasing use in various industries in the past few decades. This tendency is expected to continue in the future, especially in connection with emerging industries and involving both large and small physical size applications, such as gear drives for wind farms for renewable power generation, for instance. Certain obvious advantages of trochoidal gearing will be apparent to the reader by reviewing the sample examples provided in this article. For further information on the subject of trochoidal and cycloidal gearing, the reader is urged to review Reference 1, which is cited at the end of the article.

Certain curve-linear functions have been used to approximate involute and trochoidal gear tooth profiles, especially for slow moving and large gear drive applications. Readers with interests in these realms of gear design should also review Reference 1 (see sidebar References, page 42).

Sample Examples on ACADS

Illustrative examples on using ACADS appear in the following sections, which include:

- speed reducers
- indexers
- geared four-bar linkage mechanisms

A limitless number of other specific application areas for ACADS will be found by gear and gear mechanism designers, some of which have been listed in the summary.

Speed Reducers

Consider the layouts (CAD plots) in Figure 1 that will help us create corresponding ACADS animations for the respective epitrochoidal speed reducer, as a most simple and introductory example on ACADS.

The single-line left plot (or "single frame," which is a term borrowed from the movies) serves as a zero position and time reference for the beginning and the end of a motion cycle involving one full turn of the gear as an input or driving member, and a corresponding half revolution of the four-roller follower wheel as an output or driven member of the reducer. The internal-mesh type engagement of the input and output members causes the members to rotate in the same direction, as it is implied by the positive value of the ratio R=2 in this case.

Figure 1 — Two-tooth partially conjugate prolate epitrochoid spur gear reducer of parallel input/output shafts for ratio R=2:1.

Figure 2 — Photograph of epitrochoidal spur gears such as shown in Figure 1 for R=2:1 speed ratio.

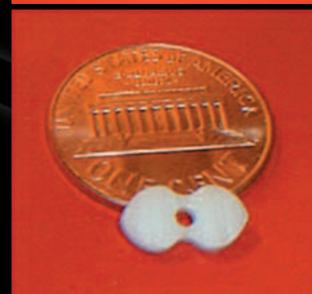

Figure 3 — Miniature version of the gears shown in Figure 2. Reduced in size to a scale of 1:16 (6.25 percent) approximately, this gear was precision cut in acetal, an engineering thermoplastic.

As in all sample examples in this paper, we assume uniform motion at constant speed for the input member, the gear in Figure 1. In this example we have used 16 frames per motion cycle. The resulting 16-frame composite plot is shown on the right side in Figure 1. The opening (zero reference) frame plot, and the composite plot in Figure 1 constitute the static ACADS images, typically and dominantly the product of a design engineering effort. To the trained eyes of designers, static ACADS images are important counterparts to actual ACADS animation. A set of CAD files for the corresponding static ACADS images we refer to as an "ACADS folder," in PC parlance.

Creating an actual ACADS animated image of our reducer is an easy task for someone with Web-design skills and working tools, using the ACADS folder referred to in the previous paragraph.

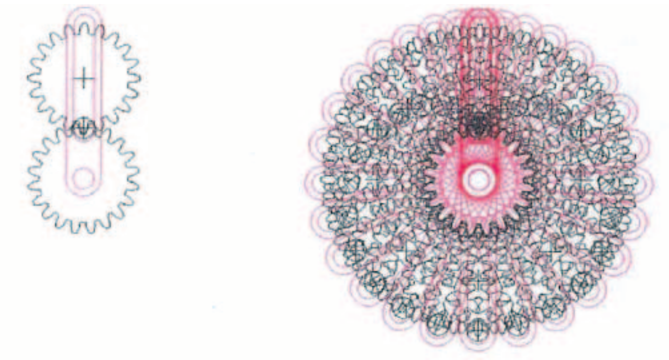

Figure 4 — Full-turn epicycloid (cardioid) indexer using two identical involute spur gears.

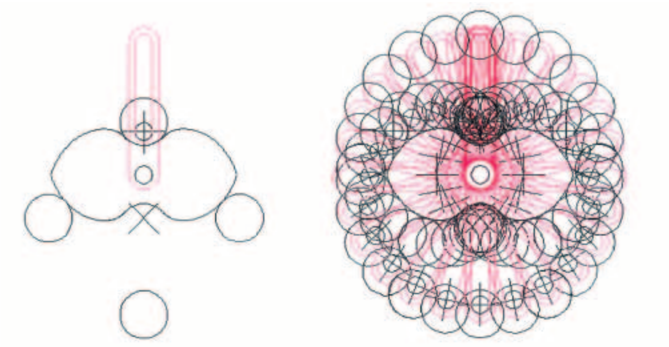

Figure 6 — Full-turn cardioid indexer using two-tooth prolate epitrochoidal spur gearing elements of internal gear mesh type we have discussed in connection with Figure 1. The crank pin is fixed onto the roller follower wheel, with its center at a radius from the wheel center to satisfy both the prolate epitrochoid gear profile and the cardioid traced by the crank pin center, for a common center distance with the wheel, as a “congruity criterion” for proper design.

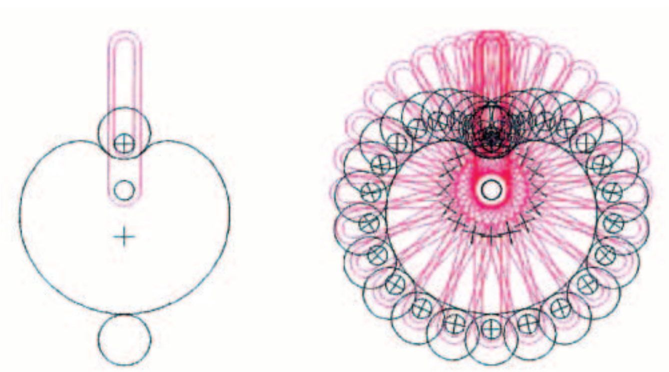

Figure 7 — Full-turn cardioid indexer using a one-lobe prolate epitrochoidal gear as a sun, in constant engagement with the corresponding two rollers of a follower wheel used as a planet. The crank pin is secured onto the planet so that the center distance between the planet center and the crank pin center satisfies the congruity criterion for the one-lobe epitrochoid and the cardioid.

The animated ACADS image cited in Figure 1 for this example can be viewed using an Internet browser such as the Microsoft Internet Explorer or the Netscape Communicator, for instance. Browsers are downloadable from the Internet free of charge.

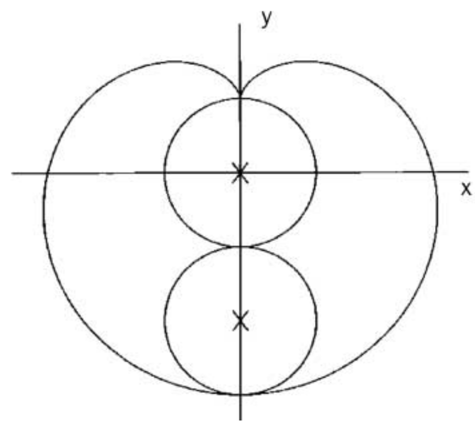

Figure 5 — Illustration of cardioid that is traced by the crank pin centers in Figures 4, 6, and 7.

For best viewing of high speed ACADS animations, however, the reader is urged to experiment with the specific browsers used, because animation smoothness can be affected considerably. We note that ACADS animations presented in this article have been created using the Fireworks animation software by Macro Media for cost-effectiveness of creating both the static ACADS folder by the design engineer, and the animated image file by the Web designer in cooperation with each other.

Higher quality ACADS animations are available at significantly higher cost, using MM’s more-sophisticated Flash rather than the Fireworks software.

HTM files on ACADS animation can be saved in individual GIF files for high quality playback on a PC using various viewers and players, such as the Windows Picture and Fax Viewer, or Quick Time Player, for instance, for slide show presentations at upper management meetings on important projects and programs, and for many other uses.

Gear design engineering work in conjunction with this article was done using Trogetec’s wEZGearplot CAD package for Windows and the respective software products for involute and trochoid (cycloid) gear design.

Please note that hands-on seminars on ACADS will be held at the Riverton Holiday Inn in Riverton, Wyoming, beginning in May 2004. On-site classes are available as needed.

The two-tooth trochoidal spur gears shown in the photograph of Figure 2 were released in June 2003. The approximately 4"x2"x3/16" (102 mm x 51 mm x 4.8 mm) overall size gears, precision laser-cut in 1008/1010 HRP&O stock for a bench-top automatic assembly setup, engage with 1" (25.4 mm) outside diameter rollers on 4" diameter bolt circle of a four-roller follower wheel in an internal-mesh style. These same gears are also offered as cost-effective off-the-shelf parts for experimenting by proactive engineers with an interest in the new gear design. Cost effective, custom-made versions of the gears in larger or miniature sizes are offered in virtually any material.

Full-turn Epicycloid Indexers

Gear drives of this type using external involute spur gears are discussed in connection with Figure 4.

In reference to the single frame plot in the figure, this drive employs two identical size involute gears held in a constant center distance engagement by means of a link (link not shown). The link serves as a driver or input member. One of the gears is used as a fixed sun gear of which the centerline is coaxial with that of the link and a slider crank (shown in red) with a pin. The pin is secured to the second gear so that its center coincides with the pitch circle of the gear.

The planet gear center is indicated by a "+" symbol. The single frame plot in Figure 4 represents the "dwell," or "rest" position of the drive at which the output member comes to rest for an instant while the input member keeps moving. The centers of the gears and the link are positioned along the centerline of the slider crank, and the pin center is at a common tangent point of the pitch circles of the gears.

The curve traced by the crank pin center is a one-cusp or one-lobe epicycloid, most often referred to as a "cardioid" in mathematics and kinetics, owing to its unique shape (Figure 5.) The circle with center at the origin represents the pitch circle of the sun gear in Figure 4, and the other circle represents the p.c. of the planet gear, that rolls around the former without slipping. A point on the rolling p.c. traces a cardioid as shown.

We note here that, in practical gear design engineering, it is often the creation of a design chart for a given

REFERENCES

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Baranyi, S. J., "How to Boost Servomotor Efficiency for Incremental Motion," Machine Design, Dec. 10, 1993, pp. 84-88.

Baranyi, S. J., "Multiple Harmonic Cam Profiles," ASME publication 70-MECH-59 presented at the Mechanisms Conference, Columbus, Ohio, Nov. 1-4, 1970.

Chironis, N. P., "Gear Design and Application," McGraw-Hill Book Co., 1967, pp. 354-358, 370-371.

mechanism that is our ultimate aim. Toward that end, however, the road is through the organized and structured process of ACADS, while the actual animated image and composite plot results themselves may be of little importance. In contrast to this, animated images of complex mechanisms can greatly simplify our grasping or describing the operation principle of the mechanism. A good example for this is provided by the analysis of three-gear drives, which we will consider in the next paragraph.

It is important to consider that the motion characteristics of both epicycloidal and hypocycloidal indexers of large number of stations (cusps or lobes) approach that of the cycloidal motion. For cycloidal motion the output displacement, velocity, acceleration, and pulse factors are respectively as, $s^*=1$, $v^*=2$, $a^*=6.283$, and $p^*=39.48$ (see References 1-3). In comparison with these, the values for cardioid motion per sample example of Figure 11 are $s^*=1$, $v^*=1.333$, $a^*=8.400$, and $p^*=229.0$

For a set of traditional epicycloidal and hypocycloidal drive designs, please refer to Reference 4.

Geared Four-Bar Linkage Mechanisms

These mechanisms became widely known as three-gear drives, or 3GD, in the 1960s (Figure 13).

A set of equations for calculating dwell point conditions for 3GDs is offered by Reference 4.

Note that, typically, the process of creating the animated ACADS image and the ACADS folder made it possible to obtain the output displacement S versus the rotation of the eccentric gear as input displacement (or, s vs. t/T) in Figure 15. Successive differentiations of

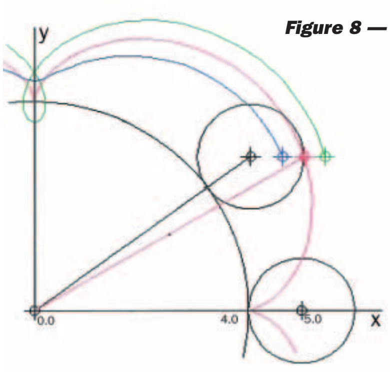

Figure 8 — Example on describing a four-lobe epicycloid, prolate, and looped epicycloid for E=1, and Q=1, 0.6 and 1.4, respectively, (see Reference 1.) The x, y tracing points and the center point of the rolling circle describe the three output displacement values corresponding to the input angle displacement of 36 degrees. For the epicycloid shown in red, the output displacement is arctan (2.93891/5.04508)=30.2221 degrees where both the input and output displacements are measured from the x-axis as zero reference. The complete curves are shown in Figure 9

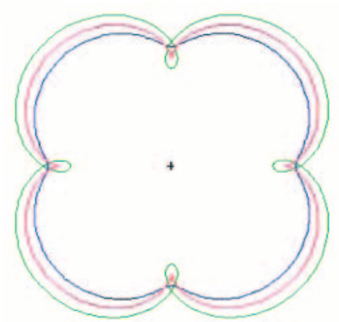

Figure 9 — Full curve plots of the four-lobe epicycloid and epitrochoids described in Figure 8.

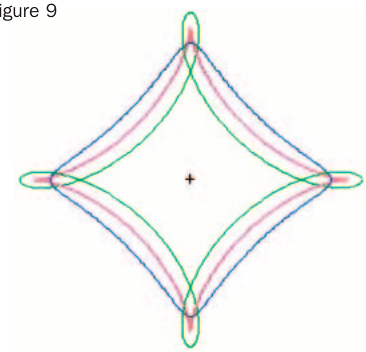

Figure 10 — Hypo-cycloidal and hypo-trochoidal counterparts of the curves shown in Figure 9.

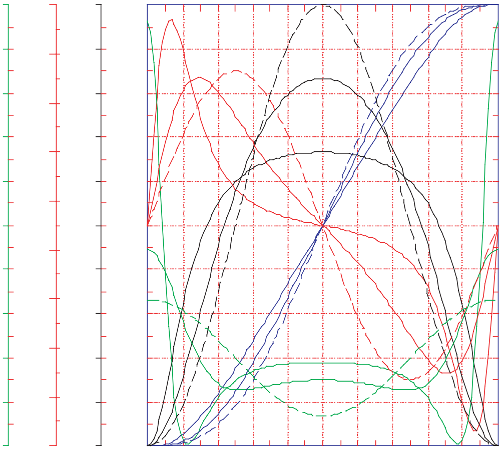

Figure 11 — Design chart for rigid epicycloid indexers, where L and T designate output displacement lift and cycle period, respectively. The term rigid simply implies that compliance effects are negligible for a given mechanism. Sample Example: A rack-pinion mechanism and a cardioid indexer comprise a linear motion drive for T=1 sec and L=10" (25.4 cm). Find maximum values of V, A and P.

Solution:

Vmax=1.333*L/T=13.33 ips (33.86 cm/sec);

Amax=8.40*L/(T^2)=84.0 in/sec^2 (213.4 cm/sec^2);

and,

Pmax=229.0*L/(T^3)=2290 in/sec^3 (5817 cm/sec^3)

S with respect to time was done numerically, to obtain the v, a, and p vs. t/T curves in Figure 15.

Finally, considering the animated ACADS image per Figure 3, the seemingly reversals of the large gear motions are actually optical illusions, similar to the rotation of the wheels of a speeding car.

Summary

Uniform input motion (constant speed), and rigid system conditions have been assumed as simplifying rather than limiting factors throughout the introductory presentation of the ACADS above. System compliance and/or non-uniform input displacement conditions in a given drive system application would make the mechanical design effort more complex (see References 2-3). However, the corresponding ACADS portion of the overall design effort would remain relatively small.

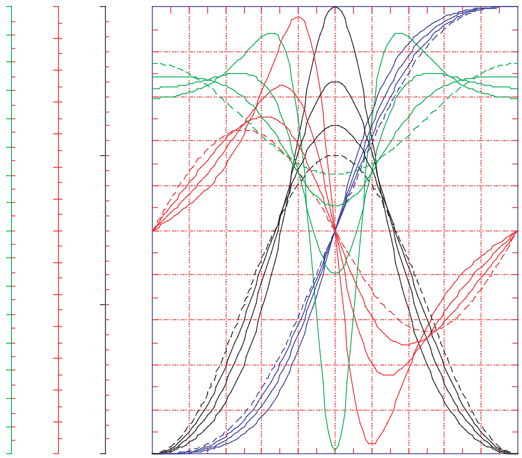

Figure 12 — Design chart for rigid hypo-cycloidal indexers.

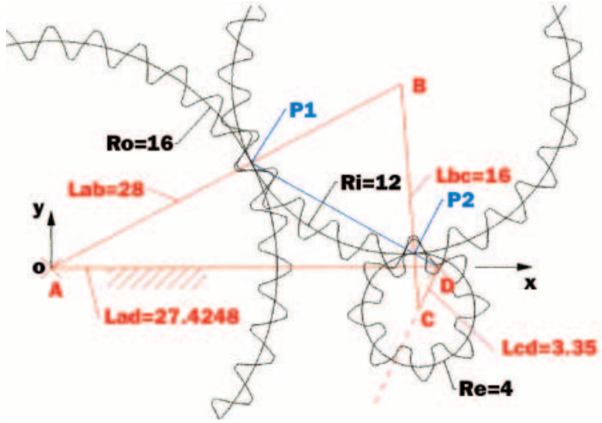

Figure 13 — Description of a 3GD setup shown at dwell position designated by the dash line in red as an extension of the eccentric (input) at dwell.

Similarly, ACADS proved to be a powerful practical design engineering tool for handling the design of composite and aggregate mechanisms obtained by coupling several component mechanisms serially or in parallel. This is not to say, however, that ACADS is not just as important in simplifying certain existing designs in the continual quest of new and improved mechanical drive products involving gears, cams, power screws, and linkages, etc.

In reference to gear design—and special gear designs in particular—at the component level, ACADS has been found useful in the following situations:

- determining contact ratio

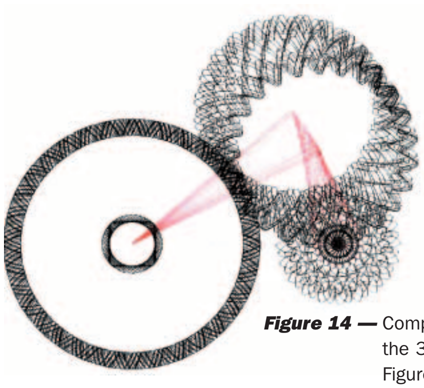

Figure 14 — Composite plot for the 3GD example per Figure 13.

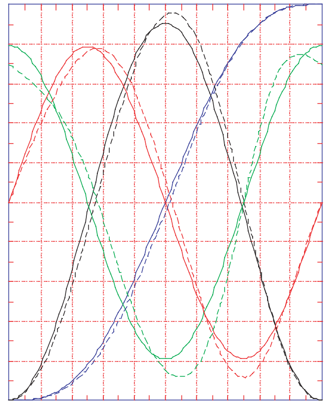

Figure 15 — Motion characteristics of the 3GD system per Figure 13, for negligible compliance effects in the drive. This design chart of the 3GD is considered to be an unprecedented result, thanks to ACADS.

- avoidance of profile undercutting
- avoidance of fouling
- gearmesh efficiency
- proving studies of various types
- convex/concave profile enveloping for external helical gearmesh
- convex/concave profile enveloping for internal helical gearmesh
- skewed profiles
- other applications

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