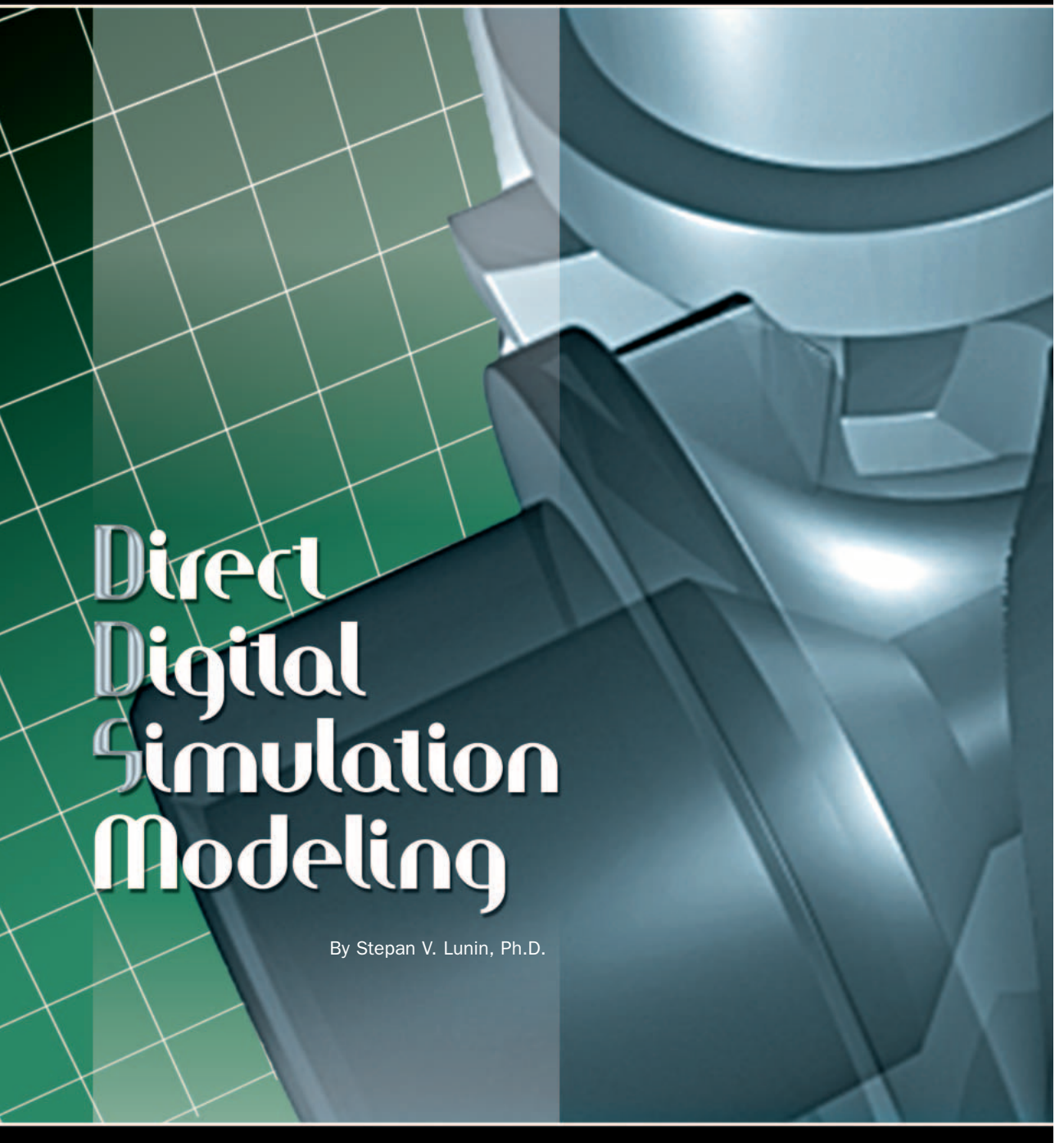
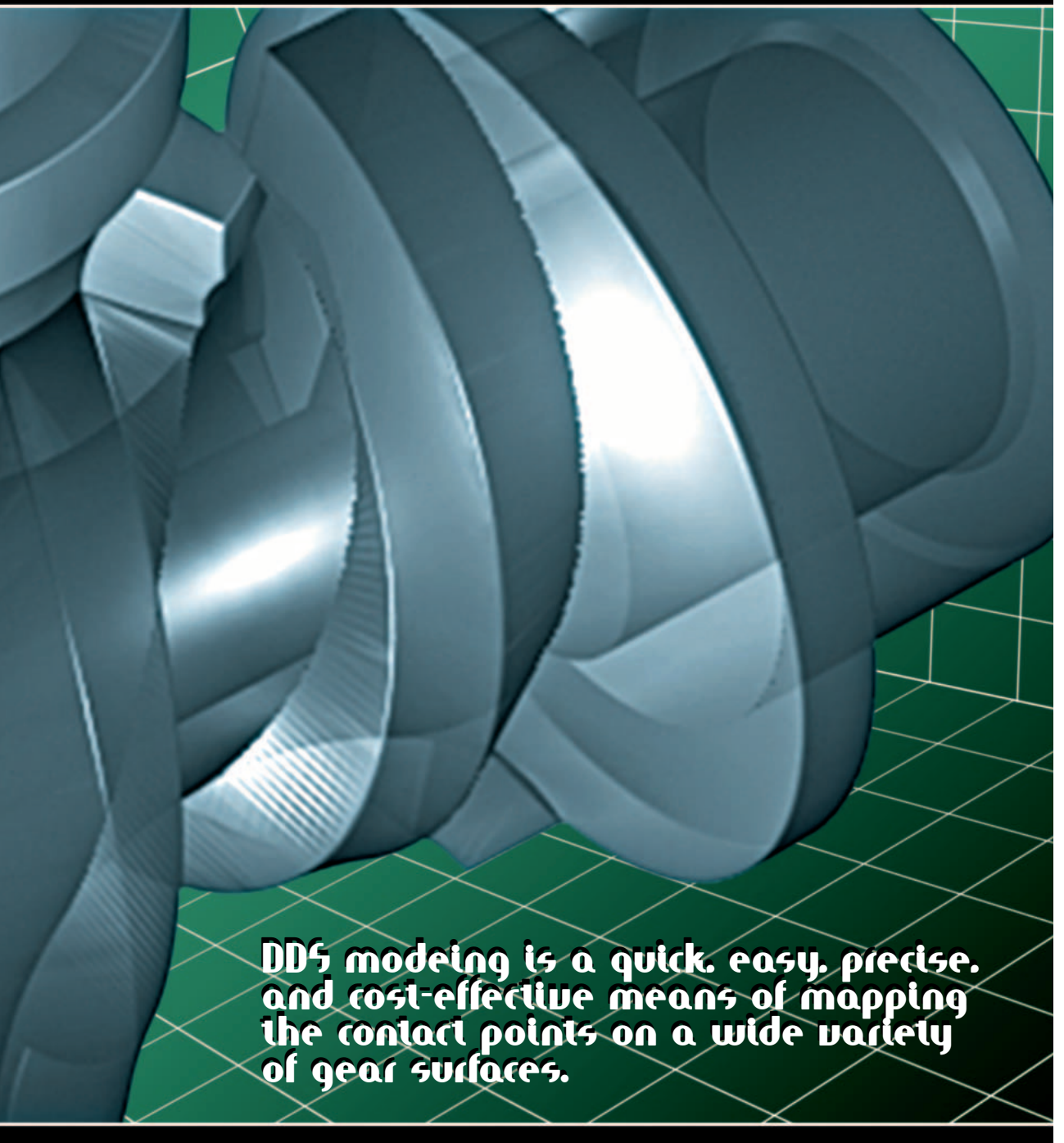


Direct Digital Simulation Modeling

By Stepan V. Lunin, Ph.D.


DDS modeling is a quick, easy, precise, and cost-effective means of mapping the contact points on a wide variety of gear surfaces.

Direct Digital Simulation (DDS) is a universal method for computer modeling of gear design manufacturing and analyses. Unlike the commonly used differential geometry, the DDS method is based on Boolean operations. DDS does not require calculating first or second derivatives for finding the envelope of surfaces. The DDS method finds the envelope of the surfaces by direct digital evaluation of the domain where the moving surface leaves its footprints. The footprints are the copies of the moving surface along its pass. The copies are made with an increment as small as is necessary to achieve the required accuracy. The final envelope is calculated as a matrix of points located on the surface. The resulting matrix is used for different analyses like Tooth Contact Analyses (TCA) or stress analyses. The DDS method does not generate the equation of the final envelope. Instead it generates the digital data that can be passed directly to the commonly used engineering CAD and FEA software products.

Introduction

The author started to use the DDS method for helicopter gears in 1986. The first time the method helped to simulate a complex involute-point gear tooth designed for Mi-26 helicopter transmission at Mil Helicopter Company in Moscow.

The author has been using the simplicity and low calculation cost of the DDS method for developing gear design and analyses software for 20 years. The method was used for almost all existing gear designs. DDS was also used for writing software for gears that do not currently exist. Ultra Globoid Gear is a good example of the software development for one such gear.

The Ultra Globoid Gear did not exist before the DDS software had been written. Engineers used the DDS model for manufacturing the gear set. DDS software generated an IGES file for manufacturing a prototype of the gear on a CNC milling machine. The same IGES file was used for final inspection of the gear on CMM.

The DDS software was successfully tested on the different gear drives: spur, helical, spiral bevel, hypoid, worm face, worm, double-enveloping worm, globoid, crown-face gear, hyperbolic gear, and variable ratio rack. However, the most important value of the DDS method is its unique capabilities in digitizing and visualization. A good example of the digital advantage is the calculation of driving efficiency. Today the efficiency of a gear set needs to be evaluated more accurately than can be done using standard formulas. The formulas give an approximate value of the driving efficiency based on the middle point on the tooth surface. The DDS method is capable of calculating the driving efficiency for each location of the contact point on the tooth. For example, the DDS method can be used to improve driving efficiency on spiral bevel helicopter gears and on hypoid automotive gears. The DDS method evaluates each small element of the contact area to calculate the sliding and friction (Fig. 4.) The resulting driving

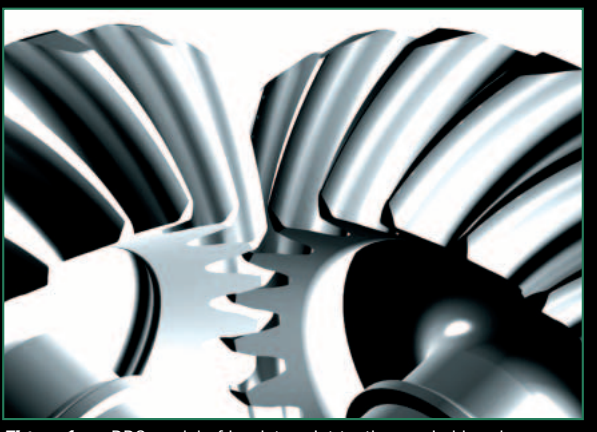


Figure 1 — DDS model of involute-point tooth on spiral bevel gears.

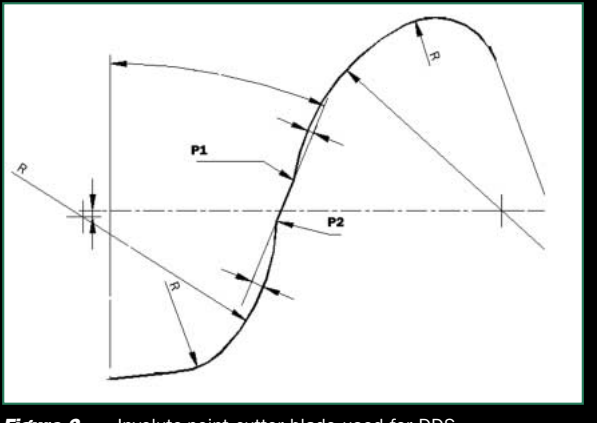


Figure 2 — Involute-point cutter blade used for DDS.

Figure 3 — DDS model of Ultra Globoid Gear.

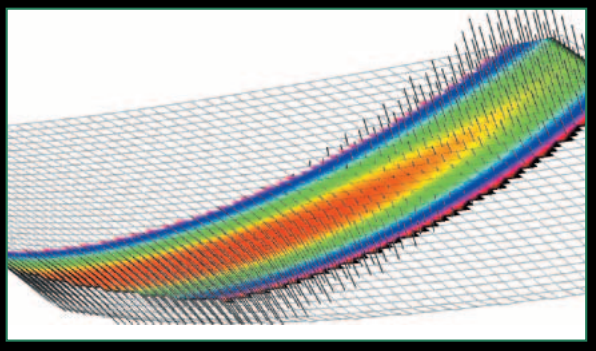


Figure 4 — DDS model of sliding vectors on the moving contact on a hypoid gear tooth.

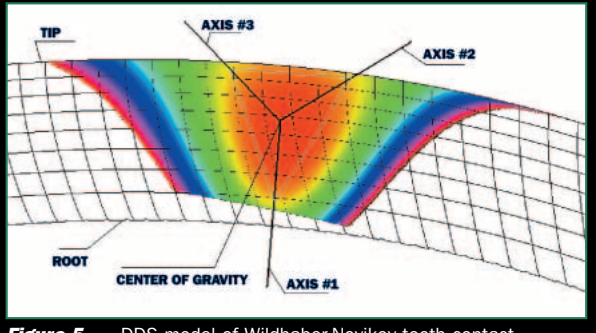


Figure 5 — DDS model of Wildhaber-Novikov tooth contact.

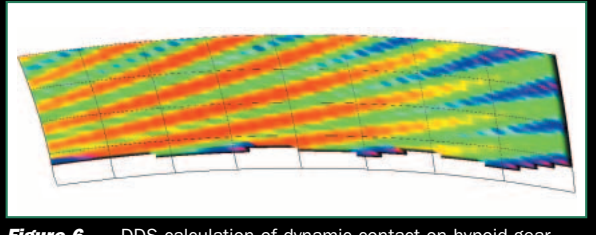


Figure 6 — DDS calculation of dynamic contact on hypoid gear with 33 x 65 resolution.

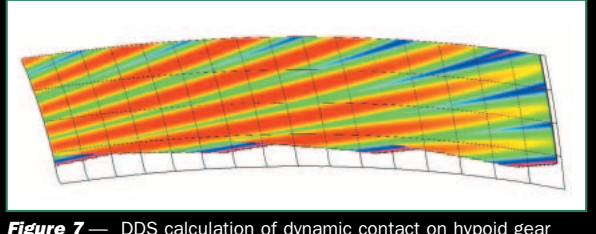


Figure 7 — DDS calculation of dynamic contact on hypoid gear with 257 x 513 resolution.

efficiency is calculated based on a summary of the friction torque on each of the elements on the tooth surface.

The discovery of the tooth contact geometry on Wildhaber-Novikov (WN) gears is a good example of the visualization value of the DDS method. Before DDS visualization, it was mistakenly believed that the contact area on the WN gear tooth is elliptical. It used to be a common error to calculate two axes of the contact ellipse for evaluation of the gear contact strength. The DDS high-resolution visualization software shows that the real contact area on a WN gear is not an elliptical shape.

It would be incorrect to call this three-dimensional domain by any of the existing geometry terms. The most important points in this discovery are the location of the center of the gravity of the contact and the wider area of the contact closer to the pitch cylinder. The center of the gravity of the contact is approximately the center of the effort of the resulting load on the gear tooth. The previous calculations were based on the elliptical form of the contact. The center of gravity of the elliptic is located closer to the center of the tooth section. This error leads to incorrect load rating of the gear tooth. The correct DDS calculation shows that the WN gear tooth is not as strong as it would be rated by the incorrect elliptical theory of the contact.

The modern technology is getting more complex and more expensive. New scientific theories are more complex and harder to understand. DDS is just the opposite. The DDS theory is simple and more understandable for writing gear engineering software. The DDS method uses the power of modern computers, and the method is progressing alongside the progress in computers.

Software Options

The DDS method helps to write better gear software, and at a lower cost. The graphical calculation results presented in this article cannot be achieved on any of the existing gear software products. The cost of writing gear software is lower because the same universal DDS programming modules can be used for different gears. Below one can see and compare the DDS software options versus other gear software products.

Resolution of DDS software is practically unlimited. A rough calculation is normally done on 33 x 65 = 2,145 elements on the tooth surface. The finite calculation can be done on 257 x 513 = 131,841 elements.

Commonly used spiral bevel and hypoid gear software provides a poor resolution of only 5 x 9 = 45 elements.

The DDS method works for any gears and any tooth forms. A good example of an advance software development is the spiral bevel gear calculation software for complex tooth form in Fig.2. The commonly used spiral bevel gear software fails to calculate the complex tooth geometry because of the discontinuity of the first derivative on some areas of the cutter profile. The DDS method does not use the derivative calculation, so the DDS successfully calculated the finished tooth geometry for the complex cutter profile.

This option is quite valuable for calculation of the total contact area and driving efficiency. The driving efficiency calculation is based on dividing the complete contact area on small elements. The total friction torque is calculated as a sum of the friction torque on each element. The DDS driving efficiency calculation allows

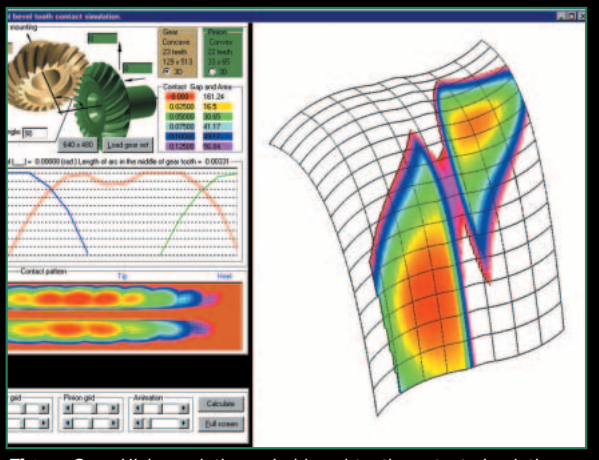


Figure 8 — High-resolution spiral bevel tooth contact simulation for complex tooth profile.The DDS method allows calculating the contact area on all the teeth participating in the contact.

comparing efficiency for similar gears. For example, the high resolution DDS software for spiral bevel gears was used for comparing the driving efficiency of spiral bevel gears manufactured with different machine settings on Gleason gear-cutting machines. It is very expensive to do the efficiency comparison of the real gears because of the very low differences. Small errors on the real test may lead to an incorrect conclusion of what gear design has higher driving efficiency. The DDS software provides practically no error in the efficiency calculation because of the high resolution of the method. The DDS method was used for developing a high driving efficiency and low-noise spiral bevel and hypoid gears.

The DDS method visualizes the removal of material from the gear blank during cutting. The DDS software calculated the cutting speed and thickness of the stock removed from the tooth surface. Different cutting processes can be simulated. The number of cutters and the feed rate determine the final geometry of the gear tooth.

The DDS method provides excellent three-dimensional visualization options. With the large number of data calculated by DDS, it is easy to use a standard visualization tool like OpenGL. All the DDS written software products carry a complete collection of standard CAD visualization options like realistic rendering, zooming, 3D rotation, transparency, and surface analyses.

Writing DDS Software

The DDS method can be used with existing CAD products like AutoCAD or Unigraphics. This is the easiest way to write DDS programs. The DDS would operate with solid CAD models by simple programming blocks. For example, a worm face gear in Fig. 12 can be cut in AutoCAD with a short AutoLISP program:

```
(while (< x pi)
(setq i (+ i 1))
(command "copy" tool "" (list 0 0) (list 0 0))
(command "subtract" gear "" (entlast) "")
(command "rotate" tool "" (list 0 0) (list (cos dt) (sin dt)))
(command "ucs" "ob" axis)
(command "ucs" "y" 90)
(command "rotate" gear "" (list 0.0 0.0) (list (cos dfi) (sin dfi)))
(command "ucs" "w")
(setq x (+ x dfi))
```

Unfortunately, the existing CAD programs are not always capable of performing very fine Boolean operations on cutting. For example, AutoCAD and Pro/Engineer give errors when performing Boolean operations on whirling of a worm face tapered pinion (Fig. 13). The CAD programs are also very slow, and it takes a great deal of time to get high calculation accuracy. The retail cost of the standard CAD software is very high and comparable with the cost of a custom multi-optional DDS program.

The DDS software is easy to extend with stress calculation options. The large number of data points on the tooth makes it easy to generate the finite element grid.

Conclusion

The DDS method has been in use in advanced gear development for over 20 years. A number of different gear software products have been developed based on DDS: spiral bevel, hypoid, worm, worm face, crown face, globoid, variable ratio rack, spur, and helical. DDS software has become an advanced three-dimensional CAD tool for gear design and analyses. The calculation and visualization advantages of DDS allow making new discoveries in gears. The DDS method helped to solve the mystery of Wildhaber-Novikov gears. For the first time, the WN gear tooth contact has been evaluated in three-dimensional space. The three-dimensional DDS visualization points out a mistaken understanding of two-dimensional flat theories. The modern demand for improving the drive efficiency of gears requires an accurate calculation tool. The DDS method provides the highest accuracy and resolution for precise calculations.

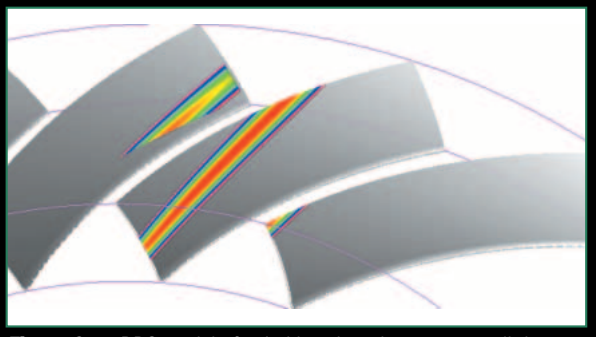


Figure 9 — DDS model of spiral bevel tooth contact on all the teeth in action.

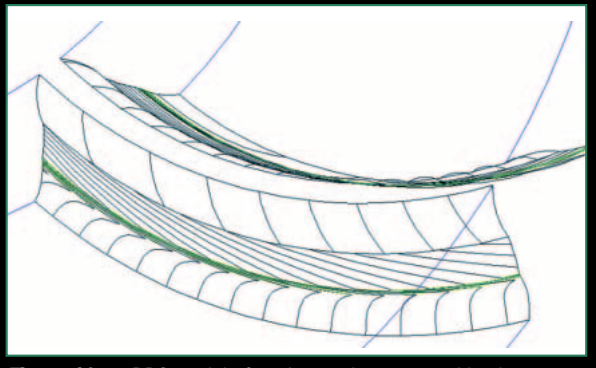


Figure 10 — DDS model of cutting marks generated by the cutter from fig. 2 on a hypoid gear tooth.

Figure 11 — DDS model of split torque crown face gear set for 21st century rotorcraft transmission.

Figure 12 — DDS model of worm face gear cut in AutoCAD.

Figure 13 — DDS model of whirling for a tapered worm.

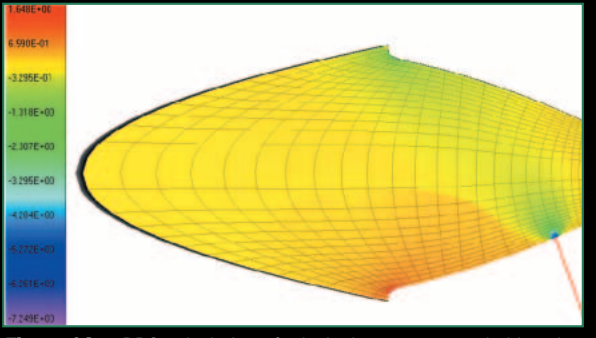


Figure 14 — DDS calculation of principal stress on a spiral bevel gear tooth section.

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