QUALIFICATION OF THE DARCO DOUBLE CIRCULAR ARC GEAR REDUCER PUMPING UNIT

by
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The circular arc gear was first invented by E. Wildhaber in the United States in the 1920's. It was later invented in Russia in the 1950's by Novikov and is now generally referred to as the Wildhaber-Novikov gear. Each inventor had some different features that make his unique. The Russians began developing the circular arc gear and were soon making production gear reducers using the new tooth design. In the 1960's, the English continued the development of the circular arc gear and began producing a helicopter gear reducer, utilizing the circular arc gear. This unit has been in production for several years and has performed as designed without problems, moreover the designer states that this single circular gear has 1.5 times the torque capacity of an involute gear pair.

Several researchers around the world have conducted research on the single and double circular arc gears. Beginning in the 1970's, the Indians conducted extensive research on circular arc gears and have shown the bending strength and Hertzian compressive strength to be two times that of the involute gears. At the University of Brussels in Belgium, researchers have demonstrated the superiority of the double circular arc gear over the single circular arc gear and determined that the smaller helix angles gave higher bending strength for double circular arc gears. The Japanese have also conducted testing on double circular arc and a similar sim-arc gear unit with very good results. Extensive research and development has been done on circular arc gears in Russia and China, both countries have shown that the double circular arc gear reducer has much higher capacity than the involute reducer. In China recent tests were conducted with equivalent gear reducers of involute and double circular arc gears. In this test the double circular arc reducer was tested for nearly 300 hours at loads a little below two times, and at two times the load capacity of an involute reducer without failure.

The data from researchers in several countries indicates there is no doubt that the double circular arc gear reducer can be made with considerably more torque capacity than an equivalent involute reducer.

THE DARCO/LS INTERNATIONAL DOUBLE CIRCULAR ARC REDUCER DESIGN

The double circular arc reducer design is the result of several years of research and development on circular arc gears. This research and development has led to a better understanding of the design methods for double circular arc gearing. Due to the nature of the loading zone on the teeth, designers have learned how to

modify the gear teeth to reduce edge loading, noise and vibration. These methods have been used on involute gears but had to be modified for circular arc gears once the requirements were known. Figure 1 shows a comparison of the contact motion for involute and circular arc gears and illustrates the need for a different type tooth modification for each gear system. Early tests by some researchers did not recognize this requirement and had poor results for the circular arc gearing. Figure 2 shows how bending strength is reduced at lower helix angles and also shows the need for length-wise modification of the tooth to reduce edge loading as the teeth come into contact.

Experimental stress analysis by researchers have shown that the double circular arc bending stress and contact stress is considerably lower than that for involute gears. Figure 4 and Table 1 show the results of photelastic stress evaluation of involute and double circular arc gears. In this comparison the double circular arc gear teeth are loaded at one point only and still show a 30% lower bending stress than the involute tooth. It is concluded from these results that the bending stress would be 50% to 100% improved utilizing the two point contact.

Tests conducted in China on double circular arc and involute gear reducers have shown that the double circular arc gearing can successfully transmit more than two times the torque of an involute reducer with medium hard gears.

The material used in the double circular arc gearing is a steel that has considerably more strength that the ductile iron used in most United States pumping units.

The bearings utilized in the Darco/LS double circular arc unit are the 2300 type which have 50% to 100% more loading capacity than the 5200 series used in other oil well pumping reducers. Since the bearing loads are similar for both type of gear reducers, the 2300 type bearings will have lives that are 4 to 10 times the life of other competing reducers.

Based on the double circular arc gear design, the improved material, and the increased bearing capability, the capacity of the double circular arc gear reducer is at least 50% superior than the competition.

EXPERIENCE OF DOUBLE CIRCULAR ARC GEAR REDUCERS

The circular arc and double circular arc gear drives have gained several years of experience which has shown that they are a durable drive system. Westland Helicopter Company in England has been flying circular arc gears on a helicopter since the late 1960's

with very good results and have shown that they can transmit 50% more torque than an involute gear. The English have also developed industrial gear reducers using circular arc gears, while the Russians have been using circular arc reducers since the 1950's with very good results.

The Chinese have utilized circular arc gears for many years and have developed many industrial reducers including oil well pumping units. They have at least one turbine driven high speed double circular arc gear drive operating at 120 m/sec with good results. In addition, the Chinese have tested double circular arc units against involute reducers and have shown a capacity greater than 2 times the involute gear drive. Many double circular arc gear oil well pumping units have been operating in the United States for the past 10 years without gear failures and with proven reliability.

CONCLUSION

* **The capacity of the double circular arc gear reducer has been proven by tests in least four countries to have from 50% to 100% more torque capacity than involute gear reducers.**

* **Ten years of experience in the United States with double circular arc gear driven pumping units have shown this design to be a very reliable and cost effective alternative to the involute type pumping unit.**

RESUME
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Mr. Dennis Townsend is the Manager of Gear Research on the staff of the NASA Lewis Research Center Mechanical Systems Technology Division. He received his Bachelor of Science in Mechanical Engineering in 1952 from the University of West Virginia. Upon graduation, he worked with the Defense Department on the design of electro-mechanical computer systems and General Electric Large Jet Engine Department on the design and development of system components for jet engine fuel lubrication and hydraulic systems. Mr. Townsend joined the NASA Lewis Research Center in 1962 and conducted design analysis and evaluation of nuclear rocket engine components for the nuclear rocket engine program.

Mr. Townsend later joined the Bearing Research Section at NASA LERC where he conducted research and analysis on bearing lubrication. In 1967, he founded the NASA LERC gear and transmission research program and conducted extensive research on gearing and transmissions. His contributions to the gear industry are significant and include advances in gear materials and processes for improved operating temperature and gear life, understanding and analysis of gear lubrication, gear thermal analysis and gear dynamic analysis.

He has authored or co-authored over seventy-five papers in the gear and bearing research area and currently serves as the resident NASA gear consultant for NASA, various United States Military groups, and numerous industrial companies.

Dennis Townsend was Chairman of the Power Transmission and Gearing Committee from 1978-1983, Associated Editor of the Journal of Mechanisms, Transmissions and Automation Design from 1978-1983, awarded the ASME Fellow Award in 1987, and serves as Chairman of the ASME Design Engineering Division for 1989-1991. He currently is re-writing the Gear Handbook of the United States.

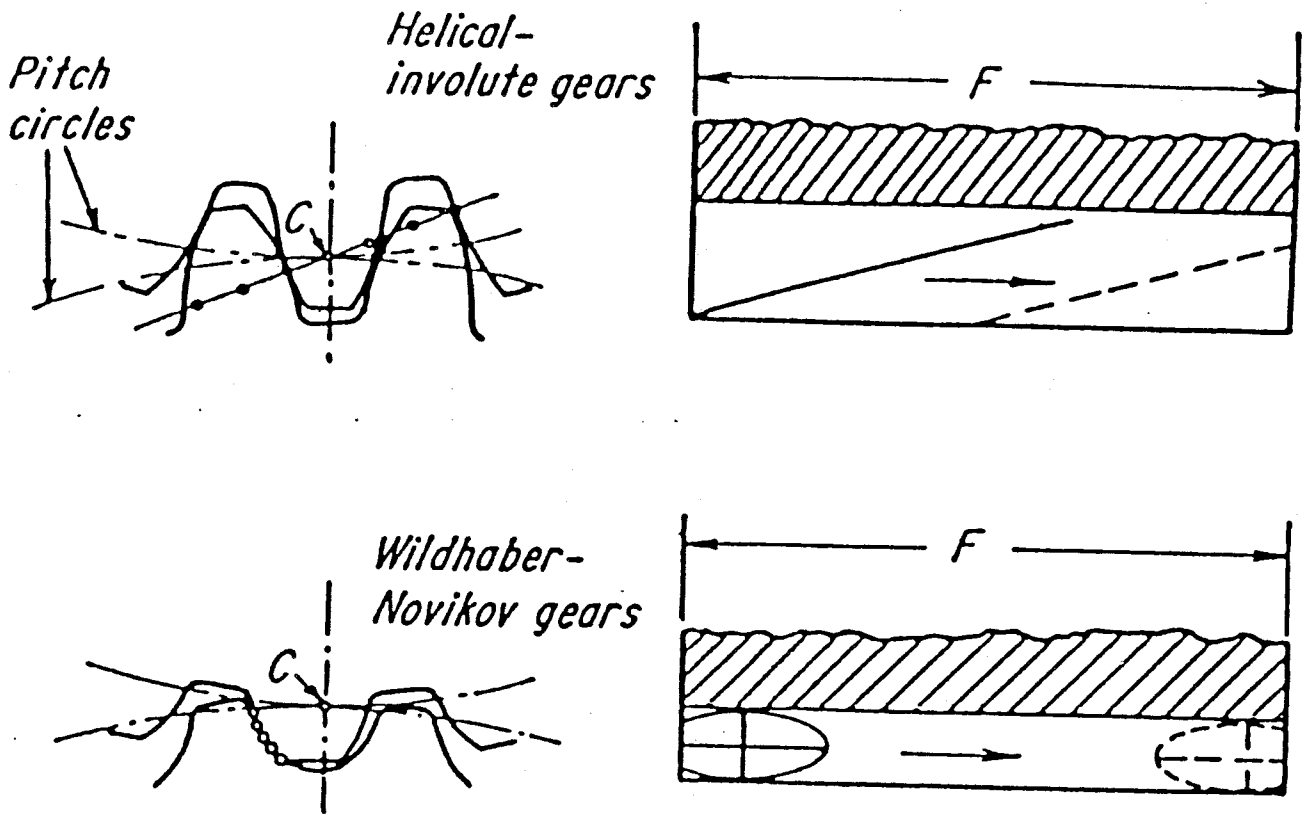
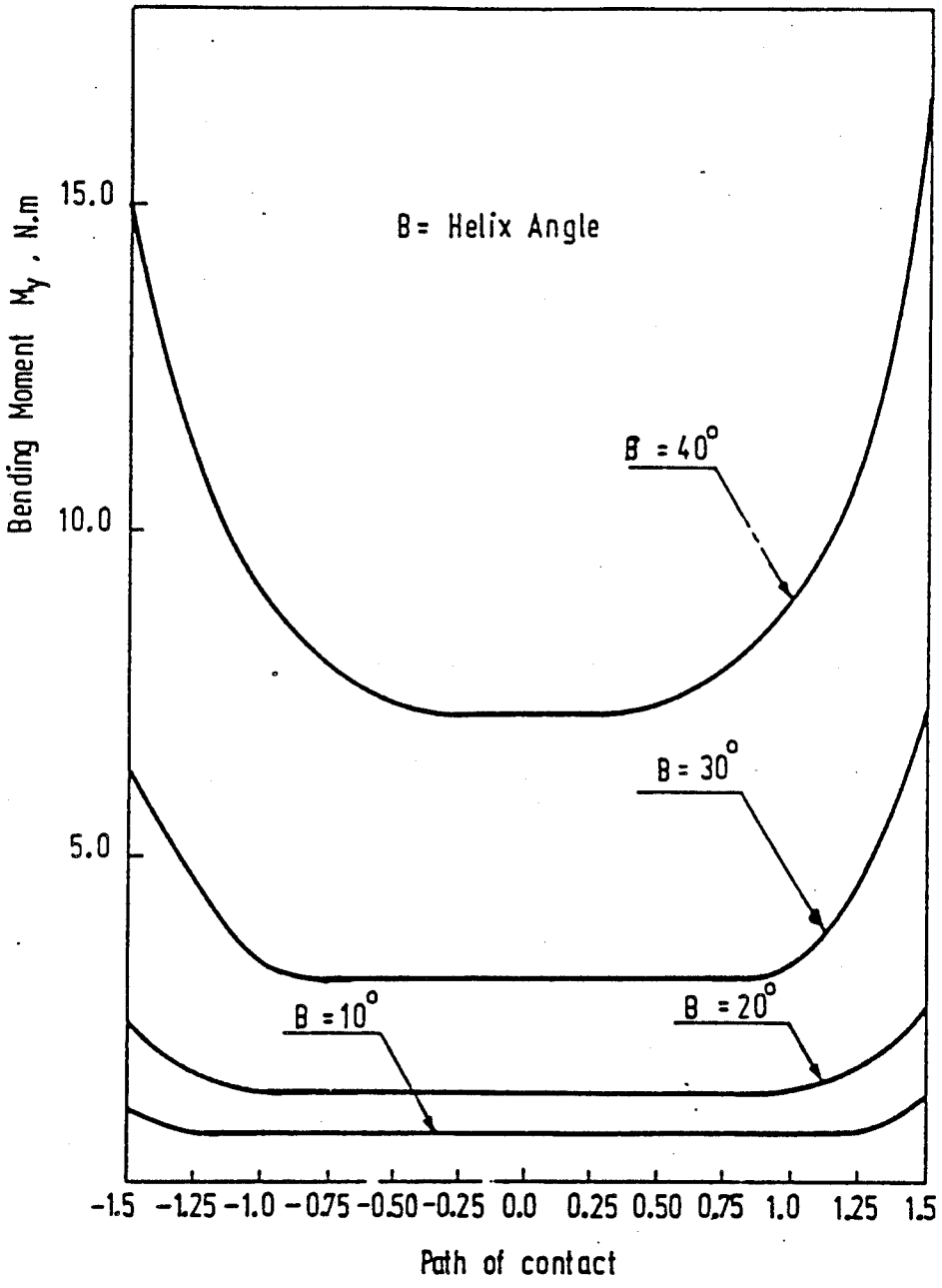


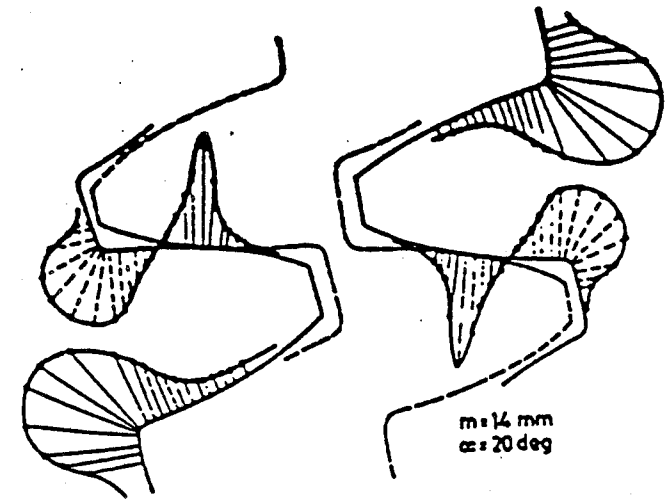
FIGURE 1.

. **COMPARISON** of helical gear systems.

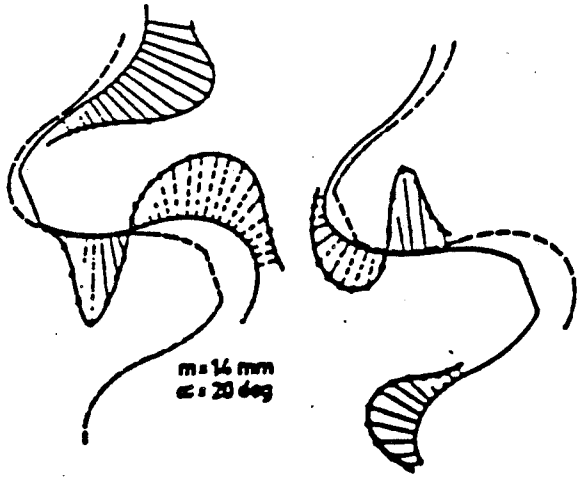


Change of maximum value of bending moment M_y, at built in edge with change of helix angle along the path of contact

FIGURE 2.

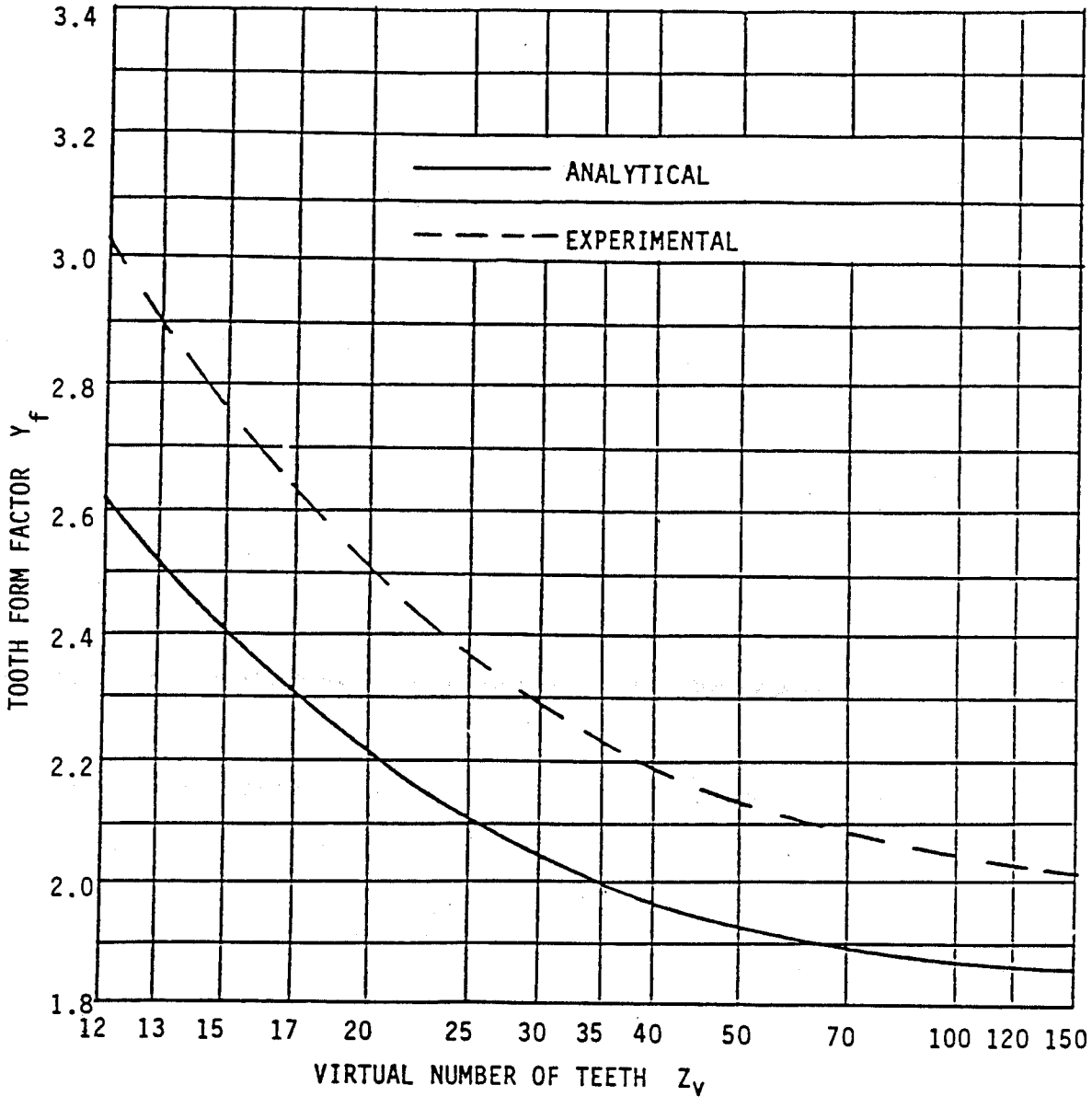


SURFACE STRESS DISTRIBUTION IN EXTERNAL INVOLUTE GEARS



SURFACE STRESS DISTRIBUTION IN WILDHABER-NOVIKOV GEARS
(ADDENDUM-DEDENDUM TYPE)

FIGURE 3.



Tooth Form Factor Y_f for Double–Circular–Arc Gear.

FIGURE 4.

COMPARISON OF BENDING STRESS FOR SINGLE POINT CONTACT

Sl No	Profile	Stress, MPa	
		Tension fillet	
		Pinion	Wheel
1.	Involute, External	571	464
2.	Circular-Arc (Addendum-Dedendum)	390	321

TABLE 1

S =Distance between points of contact across the tooth height.

H =Tooth height.

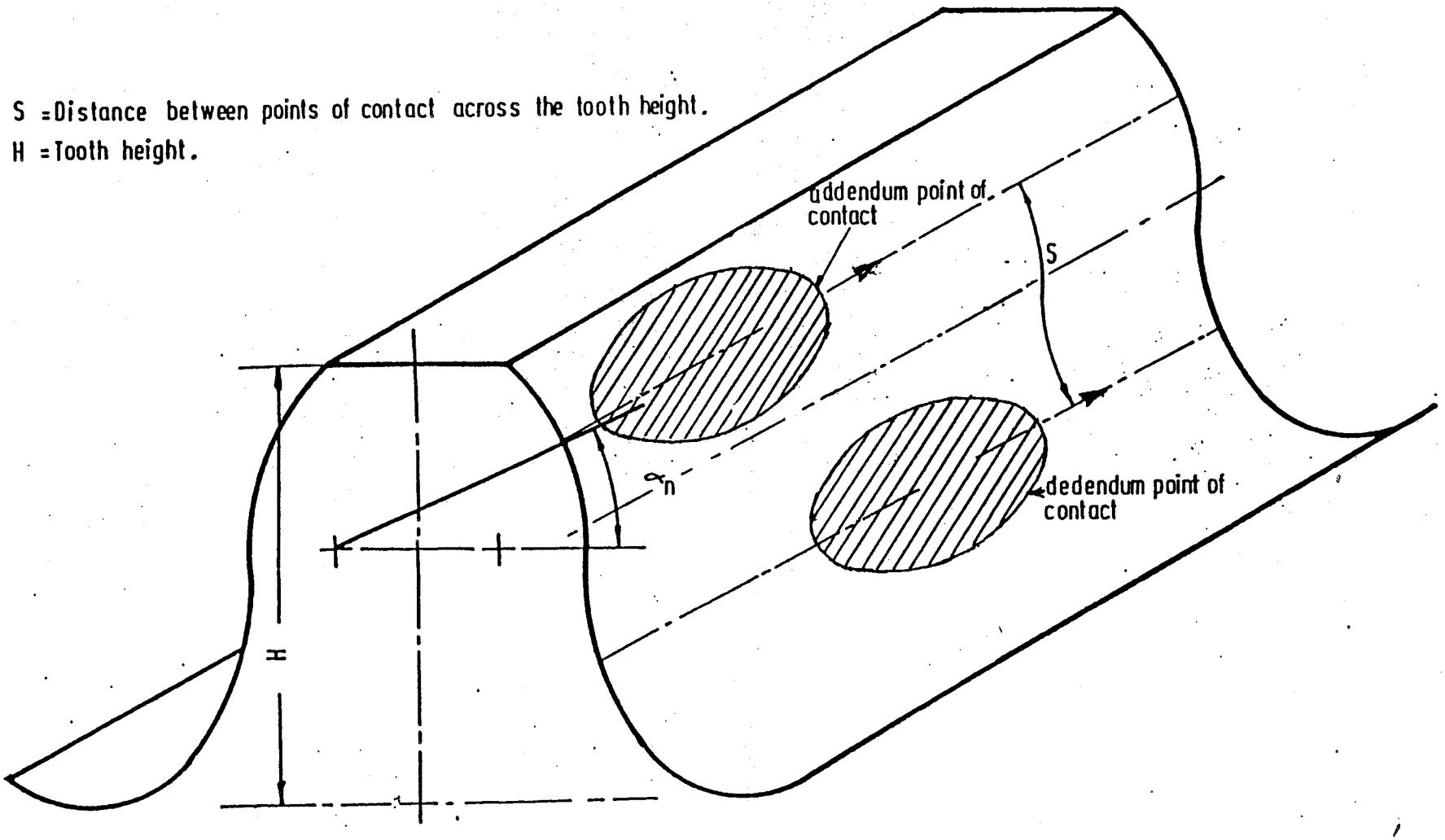


FIGURE 5.

Shows the two points of contact on the tooth face

ADVANTAGES OF THE DARCO/LS DOUBLE CIRCULAR ARC GEAR REDUCER

* HIGHER TORQUE CAPACITY-50% TO 100% OVER INVOLUTE

* LOW CONTACT STRESSES-CONCAVE/CONVEX CONTACT SURFACES OF THE GEAR PROVIDE LOWER HERTZIAN CONTACT STRESS FOR IMPROVED TORQUE CAPACITY AND LONGER LIFE

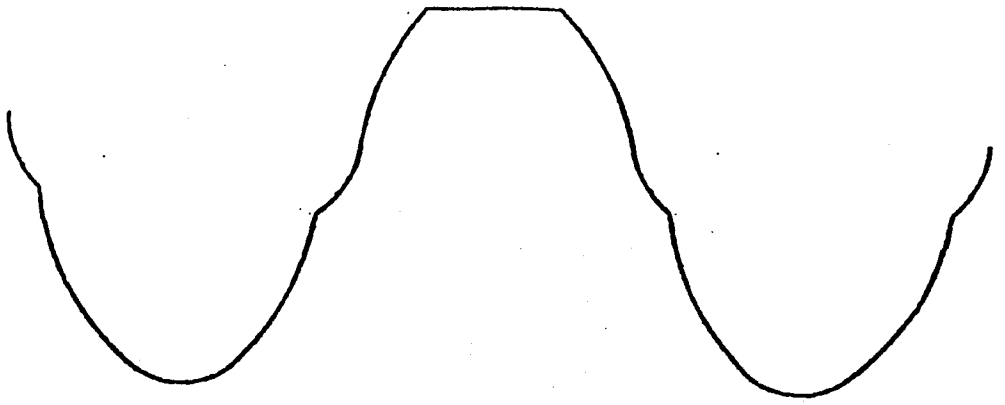
* BENDING STRESS-THE DUAL CONTACT, WIDE TOOTH FORM AND LARGE ROOT RADIUS OF THE DOUBLE CIRCULAR ARC GEAR, PROVIDES A HIGH BENDING TORQUE CAPACITY

* STEEL GEARS HAVE HIGHER STRESS LIMITS THAN DUCTILE IRON GEARS USED BY OTHER OIL WELL PUMPING UNITS

* EXCELLENT EHD OIL FILM IN THE CIRCULAR ARC GEARS PROVIDES BETTER LUBRICATION, LOWER FRICTION, AND IMPROVED EFFICIENCY. TESTS BY AEI IN ENGLAND SHOWED EHD FILM THICKNESS TO BE 3 TO 4 TIMES THAT FOR AN INVOLUTE GEAR

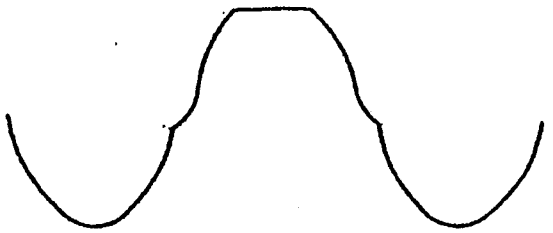
* PROVEN HIGHER CAPACITY OF DOUBLE CIRCULAR ARC GEARS BY RESEARCHERS FROM SEVERAL COUNTRIES SHOWED TESTING RESULTS OF 50% TO 100% GREATER TORQUE CAPACITY

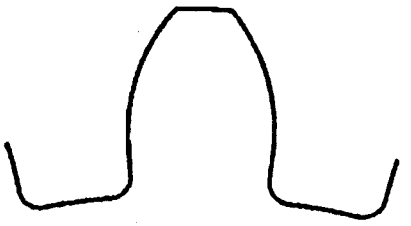
* HIGH CAPACITY ROLLING ELEMENT BEARINGS PROVIDE 4 TO 10 TIMES THE LIFE OF OTHER OIL WELL PUMPING UNIT REDUCERS



STEEL DOUBLE CIRCULAR ARC GEARS

- STRONG, STABLE, WIDE BASE TOOTH PROFILE
- TWO POINT TOOTH CONTACT
- PITTING, SCUFF, AND FATIGUE RESISTANT





DOUBLE CIRCULAR ARC

* WIDE BASE TOOTH
  STRONGER - MORE STABLE
  LOWER TOOTH ROOT STRESS

* TWO POINT CONTACT
  LESS WEAR
  LOW CONTACT PRESSURE
  GOOD LUBE EHD FILM

INVOLUTE

* NARROWER BASE TOOTH
  WEAKER - MORE DEFL.
  HIGHER TOOTH ROOT STRESS

* SINGLE POINT CONTACT
  MORE WEAR
  HIGH CONTACT PRESSURE
  LESS LUBE EHD FILM

EXPERIENCE OF DOUBLE CIRCULAR ARC GEARING

* 1958 RUSSIAN PRODUCTION UNITS OPERATING IN SEVERAL INDUSTRIES

* 1968 CHINESE PRODUCTION UNITS OPERATING IN MANY INDUSTRIAL APPLICATIONS

* 1962 ENGLISH PRODUCE CIR-ARC REDUCER

* 1967 CHINA STARTS PRODUCTION OF DCA GEAR REDUCERS

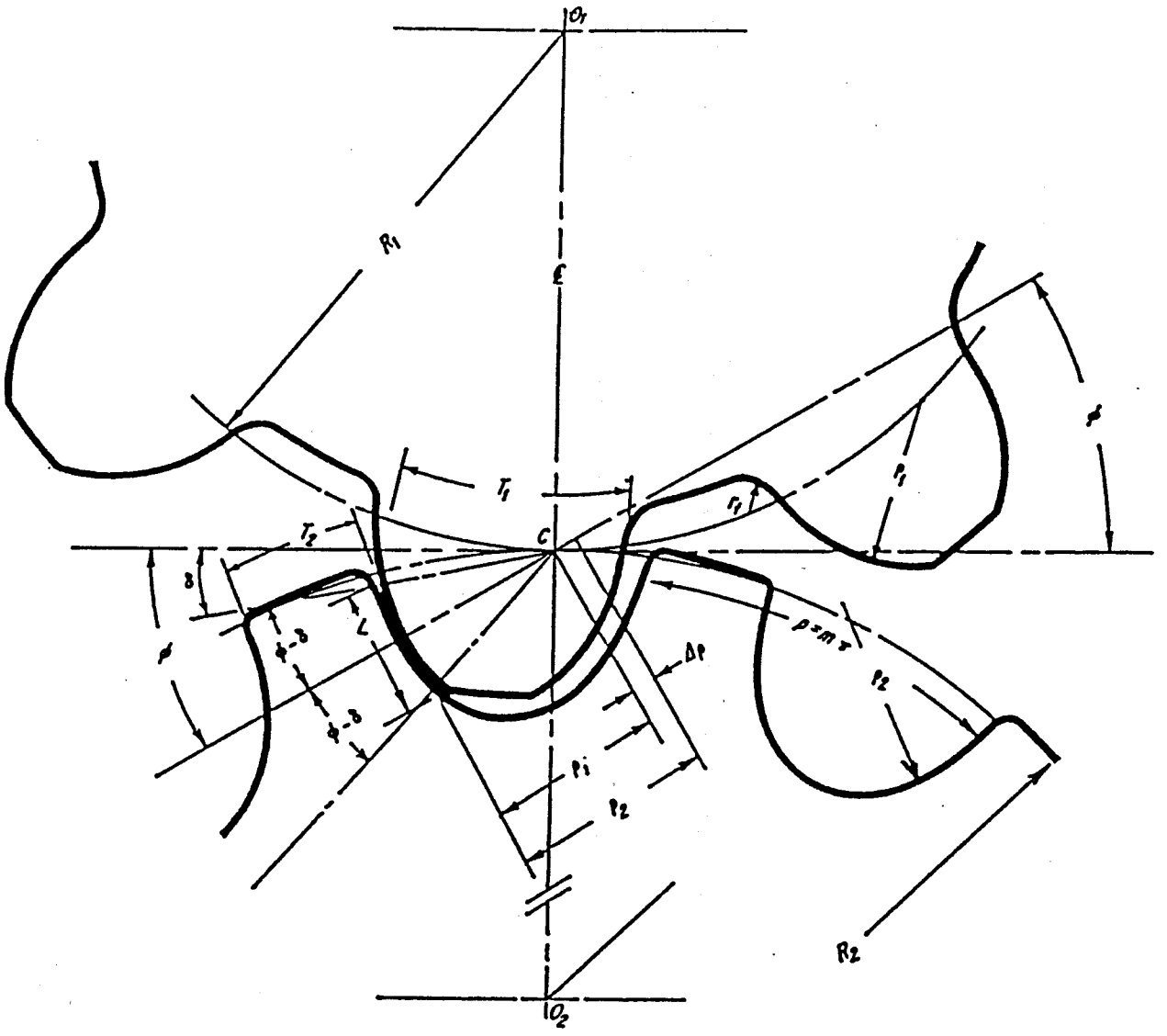
* 1968 WESTLAND HELICOPTER PRODUCES CIRCULAR ARC REDUCER

* 1976 CHINA PRODUCES HIGH SPEED DCA REDUCERS

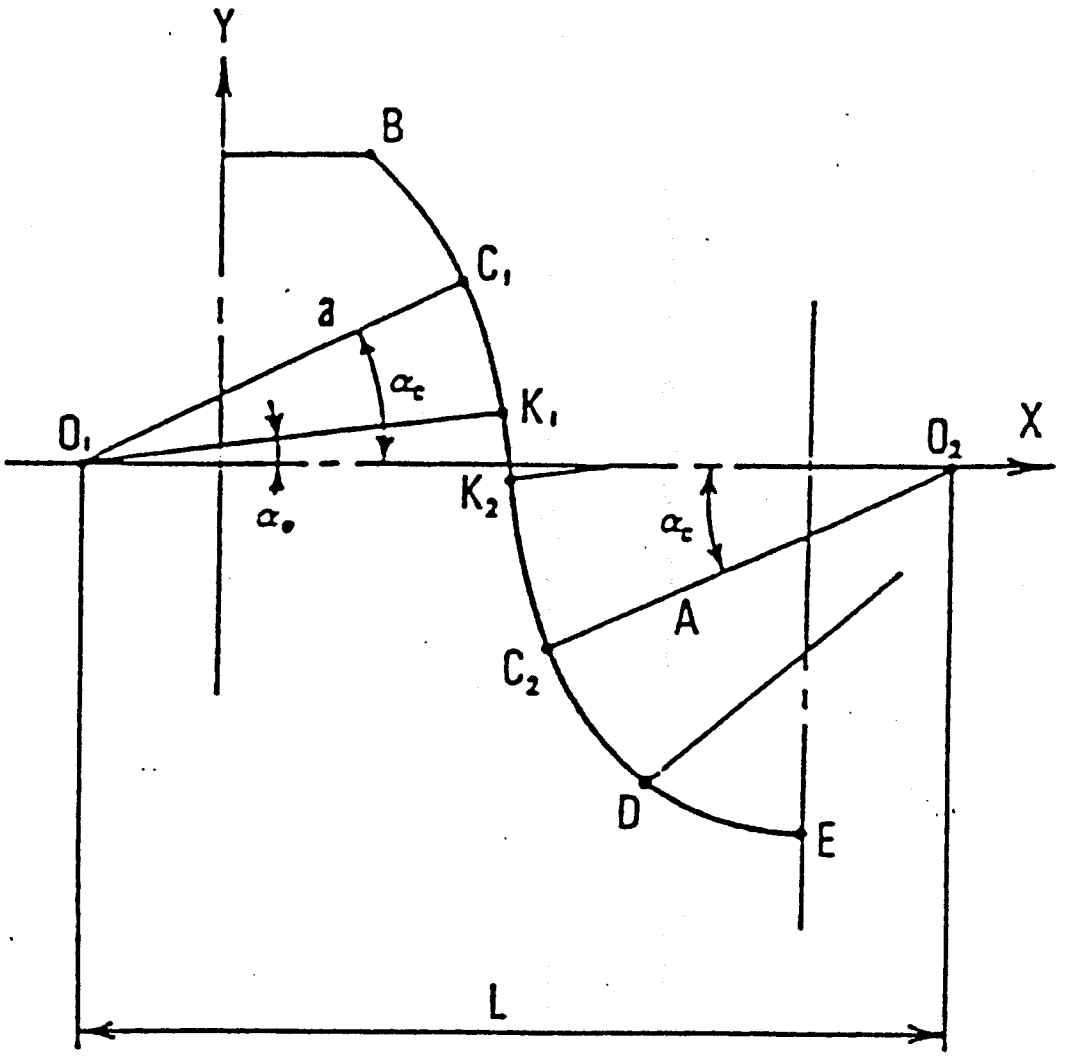
* 1980 CHINA SHIPS DCA GEAR REDUCERS TO UNITED STATES FOR OIL WELL PUMPING UNITS

HISTORY OF DOUBLE CIRCULAR ARC GEAR DEVELOPMENT

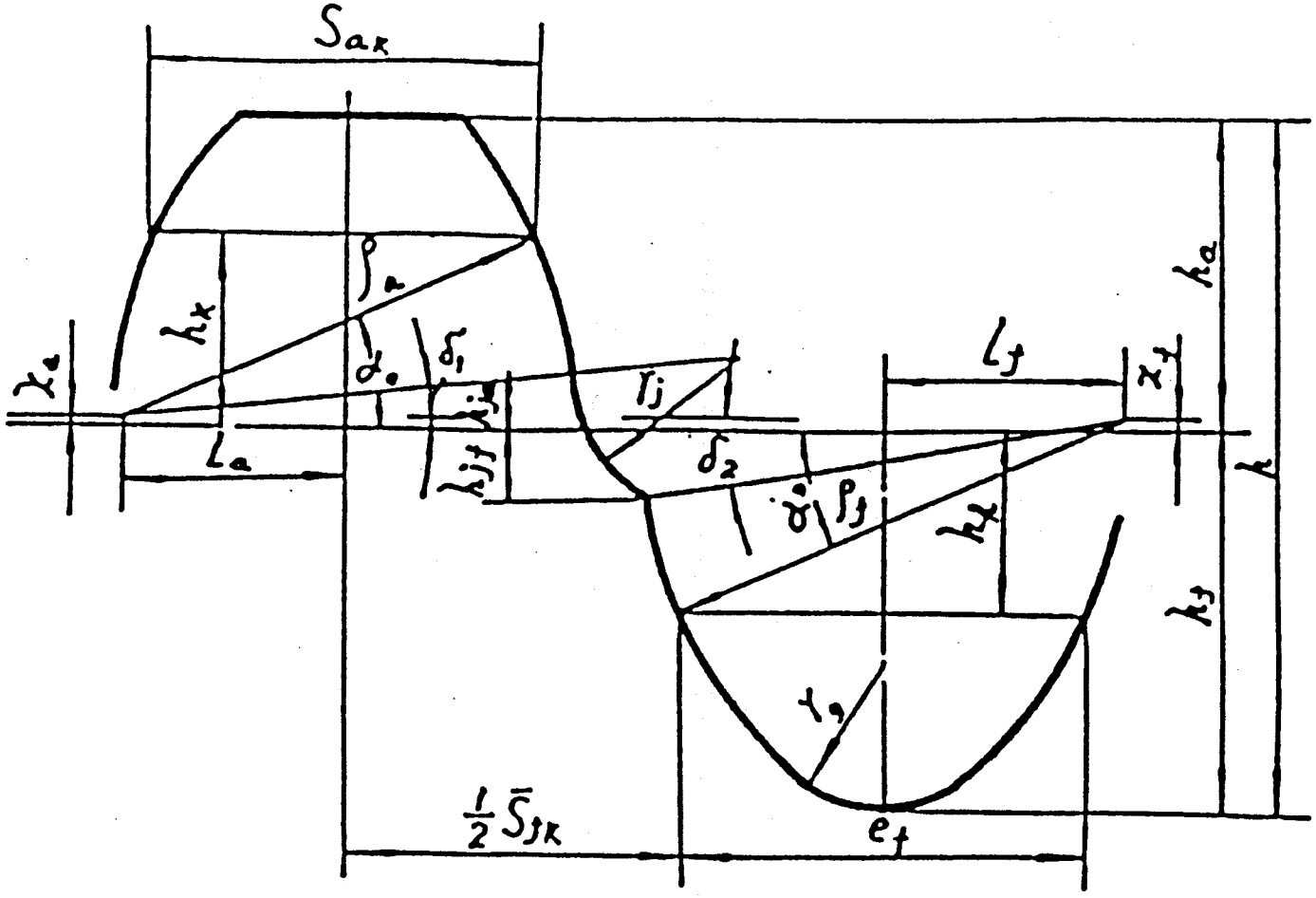
* 1926 WILDHABER U.S. PATENT
* 1956 NOVIKOV RUSSIAN PATENT
* 1958 RUSSIA ISSUED CIR-ARC TOOTH SYSTEM PRODUCTION OF CIR-ARC GEAR DRIVES
* 1958 CHINA PRODUCES CIR-ARC GEAR DRIVES
* 1960 CHINA DEVELOPS DCA DESIGN
* 1960 GERMANY STARTS DEVELOPMENT OF CIR-ARC GEARS
* 1962 ENGLISH PRODUCE CIR-ARC REDUCER
* 1967 CHINA STANDARD FOR CIR-ARC TOOTH FORM
* 1967 CHINA PRODUCES DCA GEAR REDUCERS
* 1968 ENGLAND PRODUCES HELICOPTER CIR-ARC GEAR REDUCERS
* 1970 INDIA BEGINS R&D OF CIR-ARC GEARS
* 1976 CHINA PRODUCES FIRST HIGH SPEED DCA REDUCER
* 1980 CHINA DEVELOPS DCA DESIGN ANALYSIS
* 1981 CHINA ISSUES STANDARD FOR DCA TOOTH FORM



Wildhaber Novikov (Conformal) Gear



Tooth Profile of a Simarc Gear
Combined Involute and Circular–Arc



Basic Rack Tooth Profile of Double–Circular–Arc Gear Cutting Hob