GEAR REDUCER DESIGN

The Darco USA gear reducer is the only pumping unit gear box that presently utilizes a cast steel and forged steel combination of gearing. This according to the foremost gear experts of the world is superior to the combination of ductile cast iron material against steel pinion gears, commonly used by competing pumping unit manufacturers.

In addition the Darco gear train is designed with dual high speed gears and pinions insuring a greater and more equalized loading condition upon operation. The industry's largest shafting and bearings contribute to higher safety factors, while the split gear case design allows operators easier service flexibility.

In an effort to provide an accurate non-prejudiced evaluation of our gear reducer, we have enclosed two papers which were prepared by Mr. Dennis P. Townsend, Manager of Gear Research at the NASA Research Center in Cleveland, Ohio. The first paper titled "Qualifications of the Darco Gear Reducer", was authored by Mr. Townsend; while the second paper includes test results comparing Double Circular Arc gears with that of the more common Involute style gear teeth, this test was performed in China and reviewed for authenticity by Mr. Townsend.

QUALIFICATION OF THE DARCO DOUBLE CIRCULAR ARC GEAR REDUCER PUMPING UNIT

by
Dennis P. Townsend

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.**

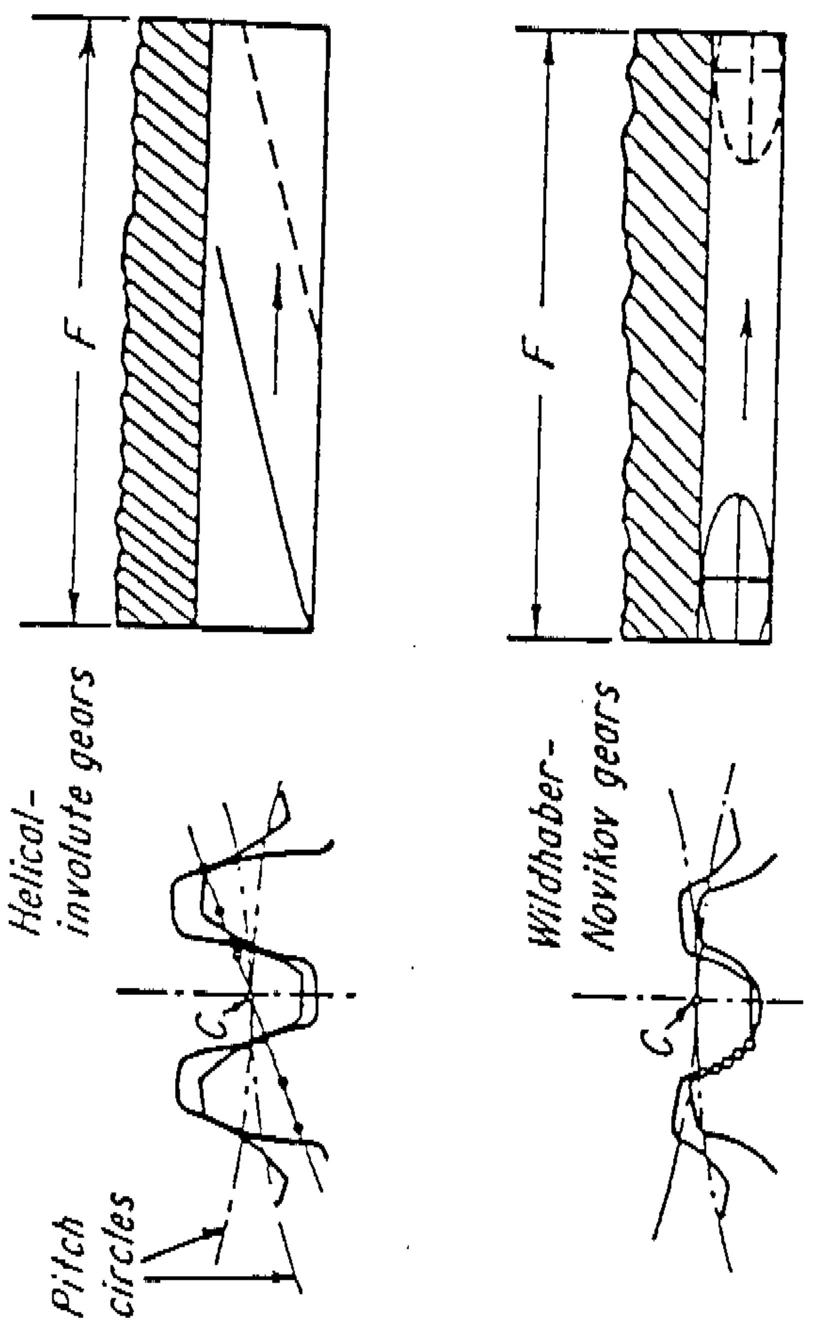
RESUME
MR. DENNIS P. TOWNSEND

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.

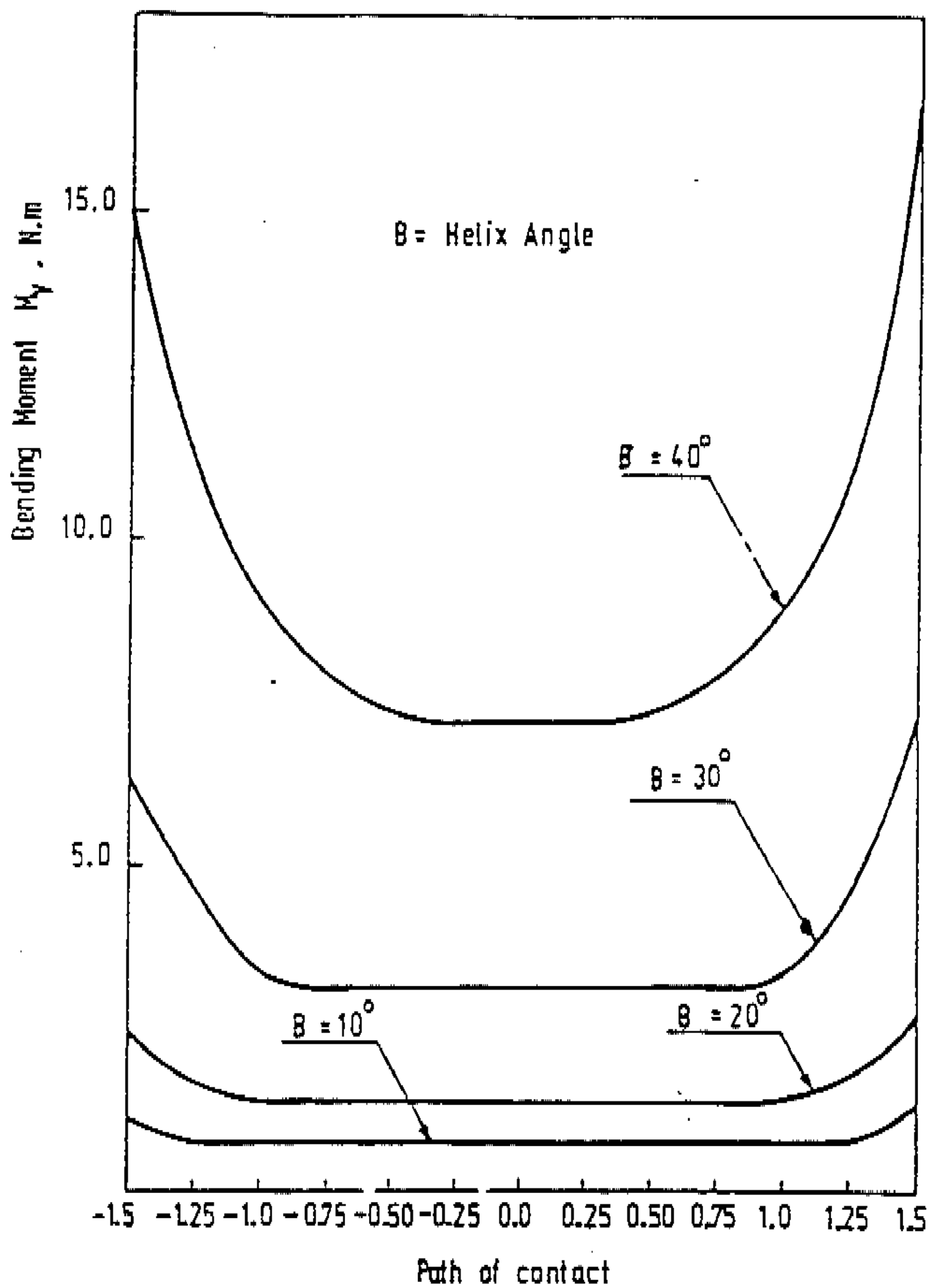
He has authored or co-authored over seventy-five papers in the gear and bearing research area and currently serves as the resident NASA gear consultant for NASA, various United States Military groups, and numerous industrial companies.

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.



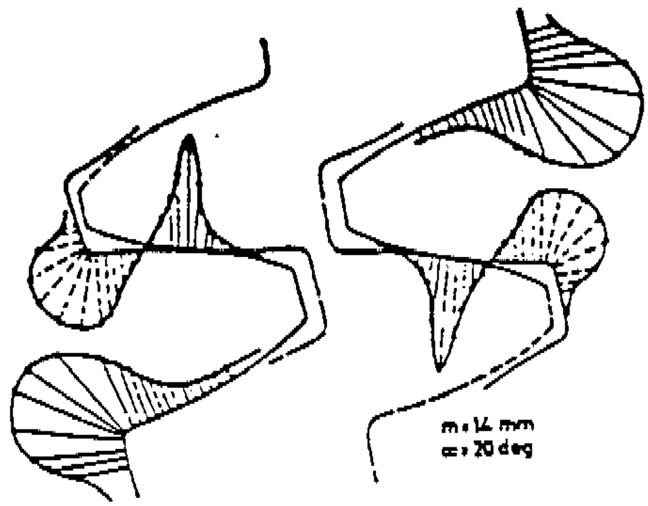
• COMPARISON of helical gear systems.

FIGURE 1.

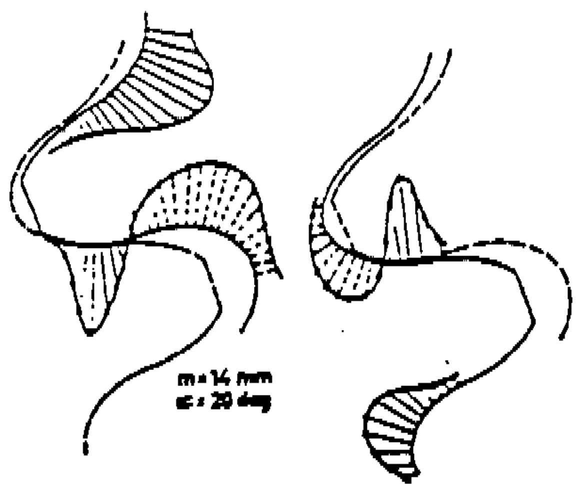


Change of maximum value of bending moment M_y, at built in edge with change of helix angle along the path of contact

FIGURE 2.

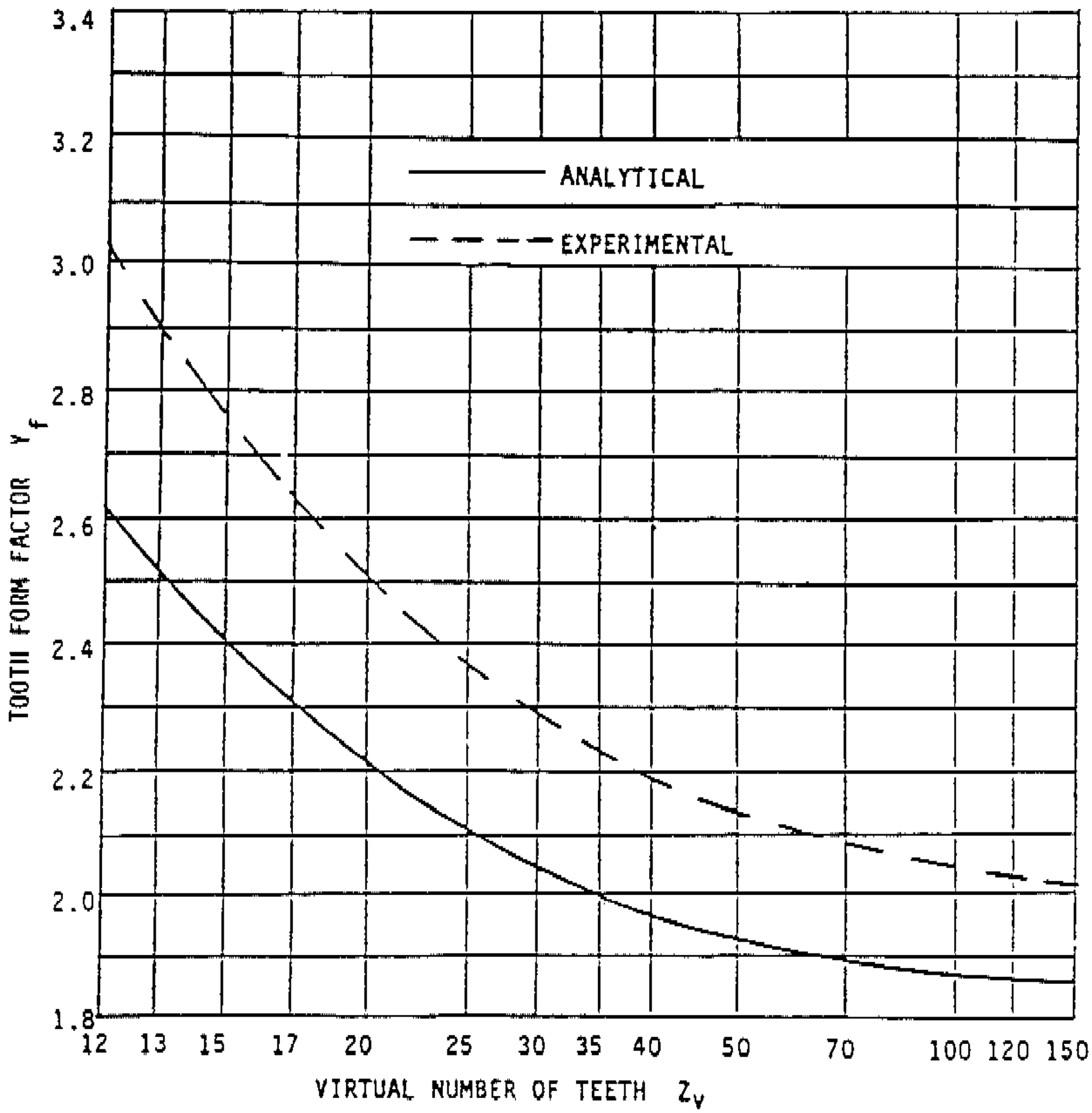


SURFACE STRESS DISTRIBUTION IN EXTERNAL INVOLUTE GEARS



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

FIGURE 3.



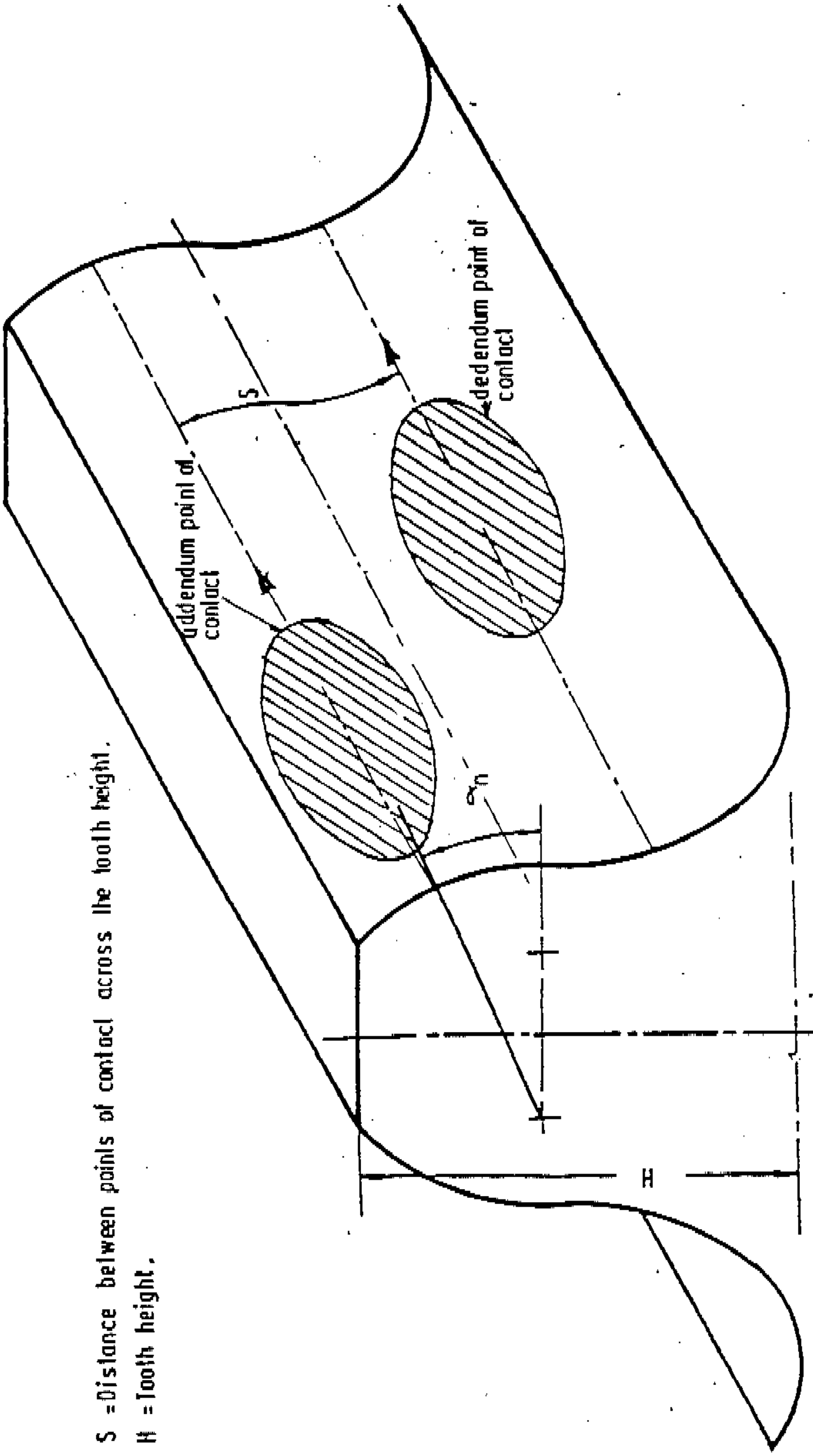
Tooth Form Factor Y_f for Double-Circular-Arc Gear.

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.

Shows the two points of contact on the tooth face

FIGURE 5.

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

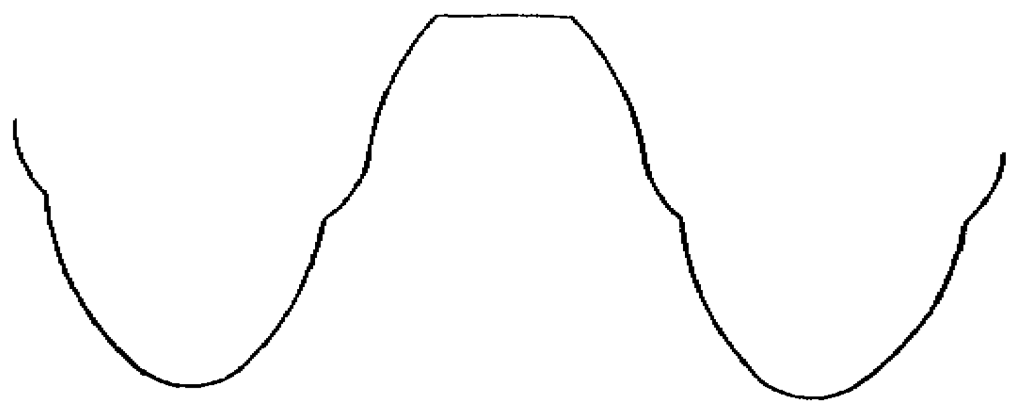
* BENDING STRESS-THE DUAL CONTACT, WIDE TOOTH FORM AND LARGE ROOT RADIUS OF THE DOUBLE CIRCULAR ARC GEAR, PROVIDES A HIGH BENDING TORQUE CAPACITY

* 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

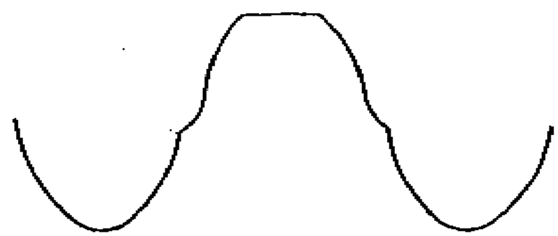
* PROVEN HIGHER CAPACITY OF DOUBLE CIRCULAR ARC GEARS BY RESEARCHERS FROM SEVERAL COUNTRIES SHOWED TESTING RESULTS OF 50% TO 100% GREATER TORQUE CAPACITY

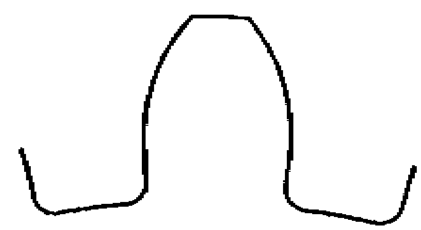
* HIGH CAPACITY ROLLING ELEMENT BEARINGS PROVIDE 4 TO 10 TIMES THE LIFE OF OTHER OIL WELL PUMPING UNIT REDUCERS



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

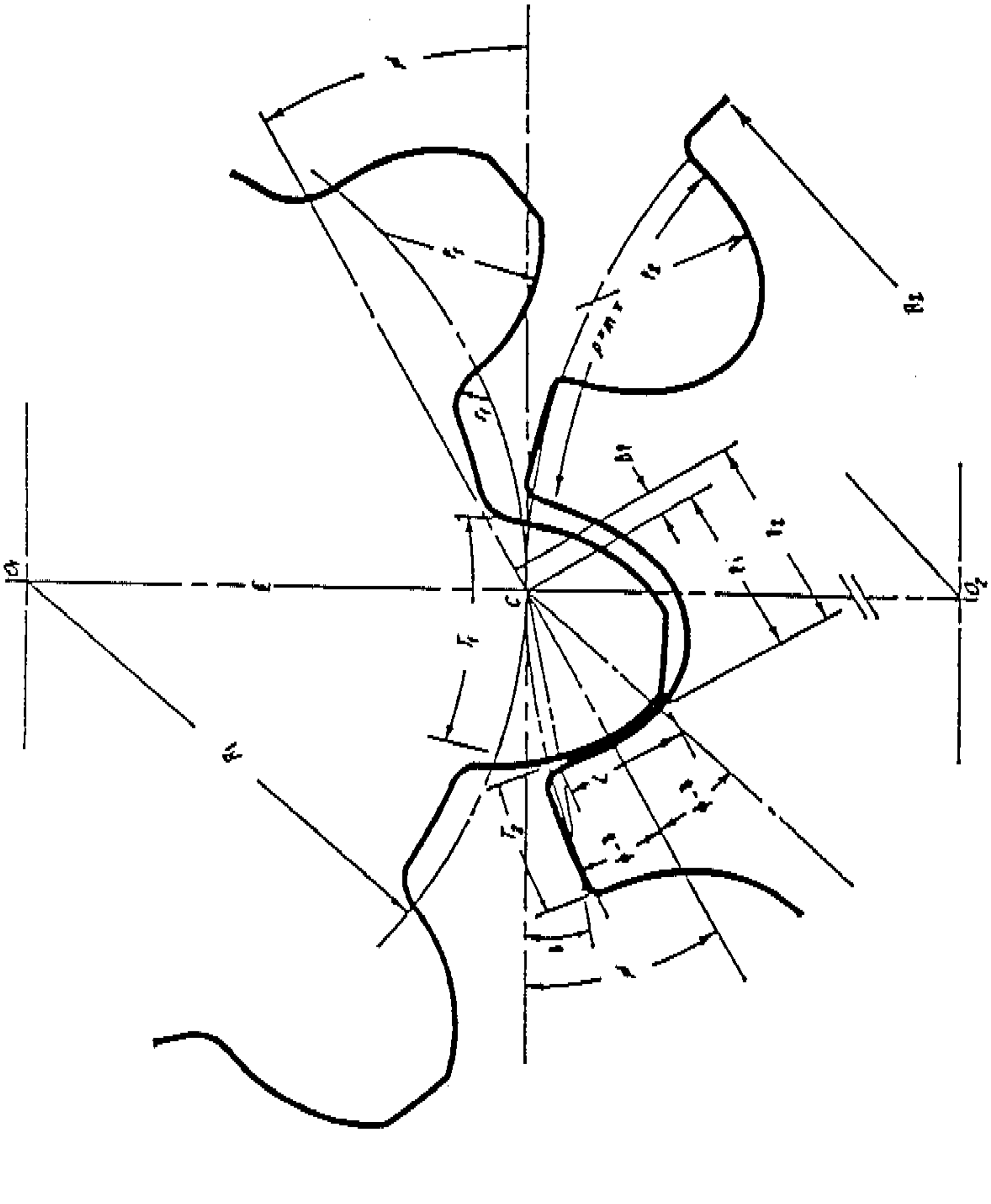
* 1968 WESTLAND HELICOPTER PRODUCES CIRCULAR ARC REDUCER

* 1976 CHINA PRODUCES HIGH SPEED DCA REDUCERS

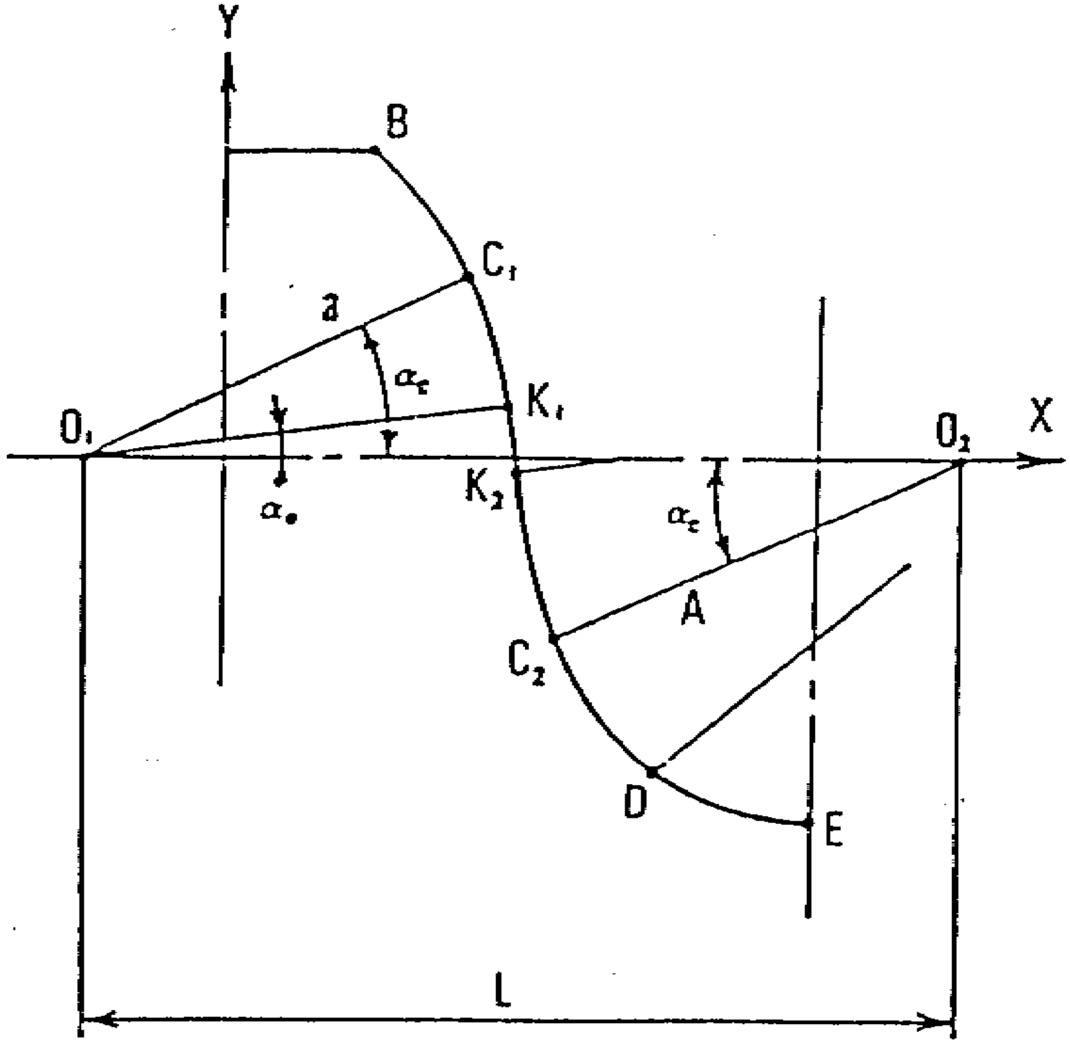
* 1980 CHINA SHIPS DCA GEAR REDUCERS TO UNITED STATES FOR OIL WELL PUMPING UNITS

HISTORY OF DOUBLE CIRCULAR ARC GEAR DEVELOPMENT

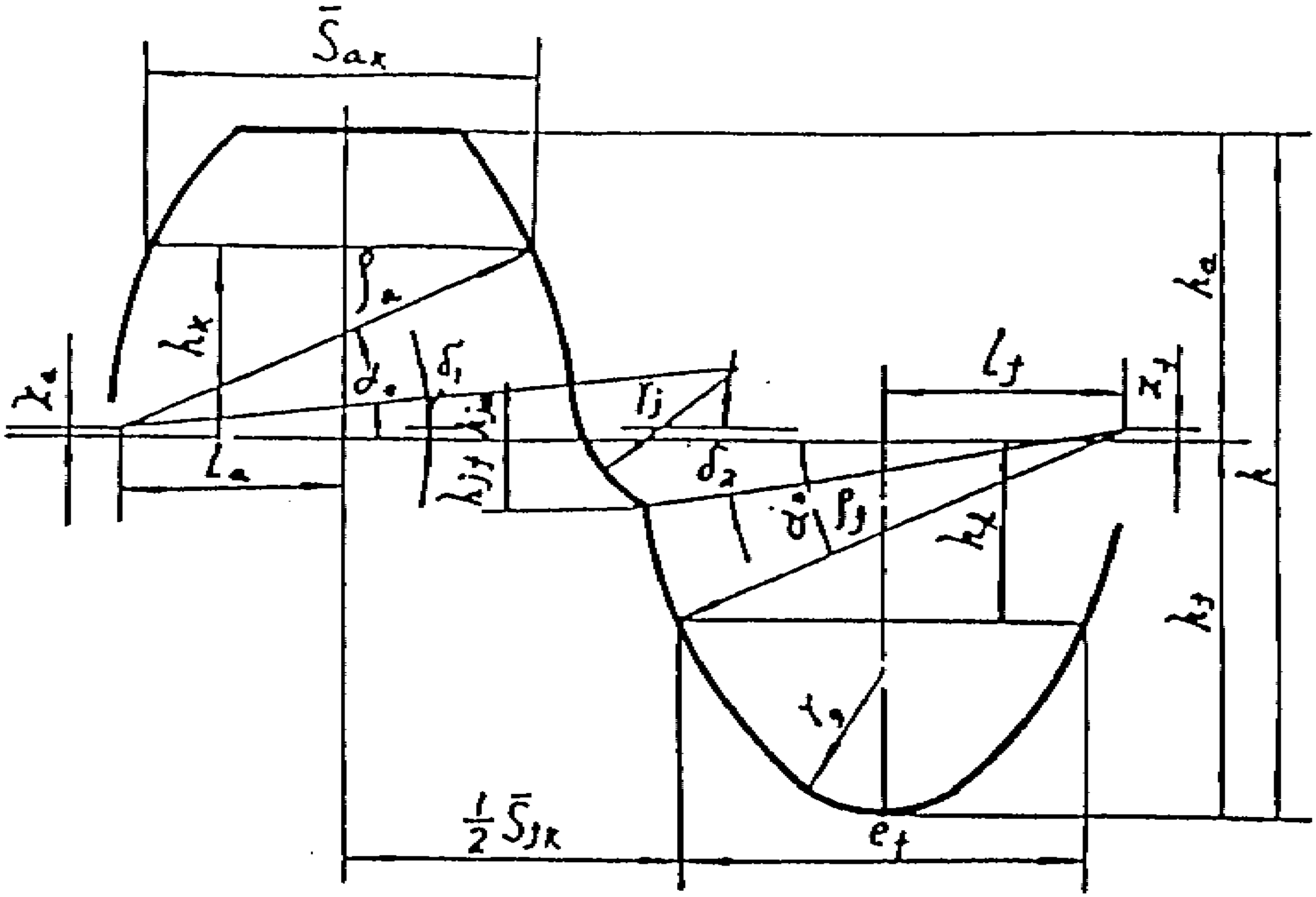
* 1926 WILDHABER U.S. PATENT
* 1956 NOVIKOV RUSSIAN PATENT
* 1958 RUSSIA ISSUED CIR-ARC TOOTH SYSTEM PRODUCTION OF CIR-ARC GEAR DRIVES
* 1958 CHINA PRODUCES CIR-ARC GEAR DRIVES
* 1960 CHINA DEVELOPS DCA DESIGN
* 1960 GERMANY STARTS DEVELOPMENT OF CIR-ARC GEARS
* 1962 ENGLISH PRODUCE CIR-ARC REDUCER
* 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

COMPARISON TEST OF DOUBLE CIRCULAR ARC AND INVOLUTE GEARS

INTRODUCTION

The main component of an oil well pumping unit is the gear reducer. During the developmental stages of the soft tooth flank involute gear reducer in the 1950's, the service life was deemed to be low primarily from tip wear of the gear teeth. In the 1960's, the single circular arc gear was developed as a replacement for the involute gear. This solved the tip wear problem, but contributed to low bending strength resulting in large, heavy gear boxes. In the early 1980's, after ongoing development, the double circular arc gear was used as a replacement for the single circular arc and involute gear. The double circular arc gearboxes showed good results and were then manufactured domestically and abroad in increased quantities.

At that time China's oil industry was producing involute gearboxes with medium hard and hard tooth flanks to reduce the tooth wear and improve the load capacity. Presently the double circular arc reducers have replaced the single circular arc and involute reducers with soft gear teeth and made these earlier designs obsolete.

There is contrasting test data for single and double circular arc gears both in China and abroad. Therefore it was decided to conduct a comparison test between a double circular arc gear reducer with soft tooth flanks and an involute gear reducer with medium hard tooth flanks. The purpose of the test was to compare the load capacity, type of failure, noise, and vibration of the two reducers with the same material, size, and test condition.

PURPOSE AND SIGNIFICANCE OF TESTS

Purpose

a. Verify the load capacity for double circular arc and involute gear reducers.

b. Determine reason of failure of the two types of gear reducers.

c. Determine the vibration, noise, and temperature rise at each load condition.

d. Compare the analytical load capacity with the test results of the double circular arc reducer and use the results to design improved lower cost pumping unit reducers.

Significance

a. Provide actual load capacity comparison between the two types of gear reducers as well as to provide data for conducting destructive tests on reducers.

b. Verify the actual load limit capacity and accuracy of the analytical formulas used for designing future reducers.

c. Institute additional steps to improve the technology of pumping unit gear reducers.

d. Improve technology to allow reduced center distance designs that meet the same technical specifications while saving large amounts of material.

e. Examine the actual load allowance for a double circular arc reducer under existing design conditions for future consideration of modification of the design parameters and machining technology. i.e., lower gear hardness can give higher gear cutting speeds and improved machining efficiency.

f. Provide a elevated understanding of the double circular arc gear and its range of potential applications.

TEST PROCEDURE AND GEAR REDUCER DATA

Test Procedure

There are two basic types of test setups that could be used, the open loop and closed loop or back to back tests. The open loop requires more power and is less economical to run for a long duration test. The closed loop test method circulates the power through the loop of the two gear reducers, with the output and the input shafts of each reducer connected to each other (see Figure 1). A method of applying torque is placed in one of the connecting shafts, usually the high speed or lower torque shaft. The complete set up of the two reducers is driven by an external drive. This method is responsible for supplying only the losses of the system, usually about one tenth or less of the circulating power of the closed loop.

The test setup was composed of one double circular arc reducer and one involute reducer connected at the output shafts by a rigid shaft and couplings. The input shafts were connected with shaft, couplings, torque loader, and torque meter. A 13.4 HP motor and belt drive was used to supply power to the closed loop test system.

Each torque load was set by the torque unit in a static condition. After one hour of operation the torque level had decreased slightly, remaining fairly constant and was recorded as the dynamic torque.

Instrumentation consisted of torque meter, thermocouple for temperature, vibration and noise measurement equipment and strain gauges for torque. The test set up is shown in Figure 1 and the reducer parameters are given in Table 1.

Standard Used To Determine Failures.

1. A gear is considered failed when it has pitting or wear over 80% of the contact surfaces.

2. A gear is considered failed if cracks are found at the gear tooth root using a magnifier.

Procedure For Double Circular Arc Gear Loading Tests

Prior to the start of the load tests, the gears are run for 10 hours at no load and 20 hours at 480 in-lb. From this test the dual contact lines can be checked for correct contact at the pitch line. If the contact is proper the test is continued.

The gear material is a steel with a hardness of HB = 300

Its basic cycle time is:

$$N = \frac{1.5 \times (HB - 30) \times 10^6}{50 - .04HB}$$

$$N = \frac{1.5 \times (300 - 30) \times 10^6}{50 - .04 \times 300} = 1 \times 10^7 \text{cycles}$$

Therefore the time needed for one basic cycle time is:

$$T = \frac{N}{60n} = \frac{1 \times 107}{60 \times 335} = 498 \text{ hours}$$

n = pinion RPM = 335

Tests were performed according to the test program up to the safe loading parameters determined from calculations and investigations of production units (see Table 2). Since the double circular arc reducer had a very high loading capacity, the first two loading steps were run for 20 and 25 hours respectively. After 70 hours at 2070 in-lb load, a few small surface pits were observed. However, these small surface pits disappeared after 193 hours at the 3341 in-lb load condition. This wear in phenomenon indicated that the surface pits were caused by some defects in heat treatment. After the final test of 130 hours at 4113 in-lb which was two times the design load and the limit load for the connecting shaft, the gears showed no signs of surface distress, pitting or cracks in the tooth root.

Eight points were considered for noise measurement. However, only four were chosen because of the interference noise from the drive motor (see Figure 1). The distance from the top surface of the gearbox to the sound pickup is one meter. The frequency spectrum of the main noise value at the highest load was 124 hz. This frequency is caused by the gear mesh frequency. The integral average noise of the double circular arc reducer was 68.1 dB(A) and the maximum single measured noise level was 73 dB(A) (see Table 3).

Reducer vibration levels were measured in three directions, the x, y and z planes for both reducers. The vibration levels in the x direction were heavier than the y and z directions.

The vibration levels of the double circular arc reducer were slightly higher than the involute reducer but the values were generally very low with a maximum value of 2.1 microns. (see Table 4).

<u>Procedure For Involute Gear Loading Tests</u>

The gear material is a medium hard tooth with a hardness of HB = 345.

Its basic cycle time is:

$$N = \frac{1.5 \times (HB\ 30) \times 10^6}{50 - .04HB}$$

$$N = \frac{1.5 \times (345 - 30) \times 10^6}{50 - .04 \times 345} = 1.3 \times 10^7$$

The time required for one basic cycle time is:

$$T = \frac{N}{60n} = \frac{1.3 \times 10^7}{60 \times 335} = 646 \text{ hours}$$

The involute gears used in this test were medium hard and they meet both AGMA and Chinese standards. They have a low safety coefficient and a history of surface distress or micropitting.

The loading tests were performed for the designed torque (see Table 5). The first two loading steps were completed without problems. On the third load test after 200 hours, some surface distress or micropitting was observed. After 200 hours at the fourth load test of 2445 in-lb, heavy surface distress was observed on 80% of the gear teeth covering an area of 30% to 40% of the tooth surface. According to the failure standard, this gear reducer is considered to be failed.

The method used to measure the noise level was the same for both gear reducers and the distance of the microphones from the gear case was the same in both tests. The average value of the noise for the involute reducer was 67 dB(A) with a maximum value of 68 DB(A), which was slightly less than the double circular arc gear reducer (see Table 6).

CONCLUSIONS

Loading Capacity

The double circular arc reducer completed six step loading tests for a total time of 599 hours. The fourth step was 45% overload for 193 hours. The fifth step was 82% overload for 161 hours. The sixth step was 107% overload for 130 hours. The double circular arc reducer completed a total of 484 hours at the 145% to 207% load condition without failure. **It is concluded that the double circular arc gear reducer has at least a 150% over design capacity.**

The involute gear reducer completed four load steps for a total test time of 652 hours. Surface distress and micropitting began to occur at 80% of the design capacity of the reducer and the reducer was destroyed at 200 hours at 106% of the design load capacity. **It is concluded that the involute reducer has a load capacity of only 80% of its design capacity.**

Noise And Vibration Of Two Types Of Reducers

The double circular arc gear reducer measured slightly greater noise levels than the involute reducer of only two dB's. The vibration of the double circular arc reducer measured slightly greater vibration than the involute reducer; however both results were extremely low with a maximum of only 81.5 μin (2.1 μm).

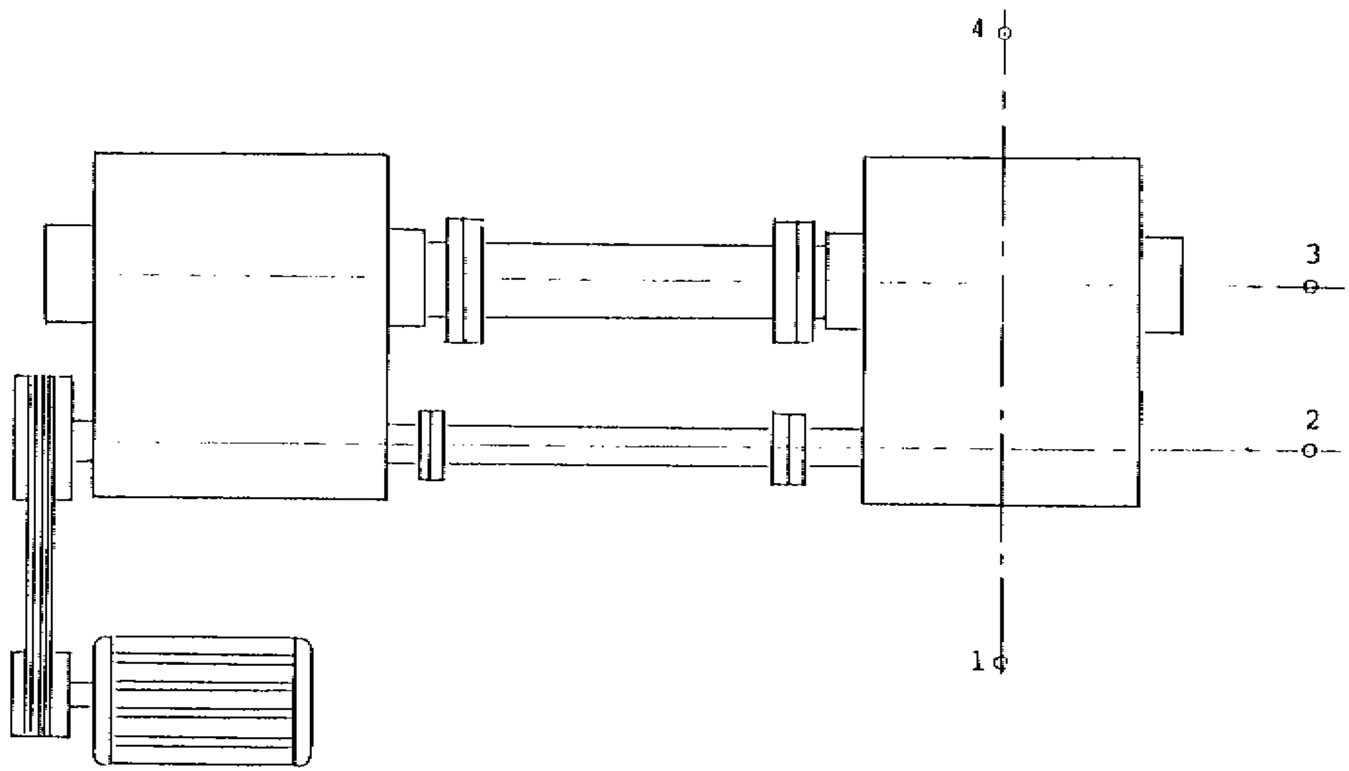


Figure 1. Closed loop test setup showing location of noise measurements

Table 1. Technical Data for Test Gear Reducers

		Involute gear with medium hard tooth flank	Double circular arc gear
Center distance	A	500mm 19.685in	500mm 19.685in
Gear ratio	i	31.73	31.73
Output torque	M_{out}	700 kg-M 60,768 lb-in	700 kg-M 60,768 lb-in
Driving shaft	M_{in}	22 kg-M 1,910 lb-in	22 kg-M 1,910 lb-in
Pressure angle	α_n	20^0	24^0
Tooth number	Z1/Z2 Z3/Z4	18/102 22/112	18/102 22/112
Helix angle	β1 β3	$25^0$50'31" $28^0$21'27"	$25^0$50'31" $28^0$21'27"
Module	Mn1,2 Mn3,4	3mm/8.47dp 4mm/6.35dp	3mm/8.47dp 4mm/6.75dp
Face width	B1,3 B3,4	45mm/1.77in 50mm/2.36in	45mm/1.77in 60mm/2.36in
Material	Z1.Z3 Z2,Z4	40CrNiMoA 35SiMn	40CrNiMoA 35SiMn
Lubricant		320# extreme pressure industrial gear oil	250# extreme pressure industrial gear oil
Heat treatment Hardness	Z1,Z3 Z2,Z4	HB340-375 HB285-320	HB280-310 HB240-270
Machining		Gear Hobbing	Gear Hobbing

Table 2. Loading Condition of Dual Circular Arc Gear Boxes

	Loading Number						
	1	2	3	4	5	6	Total
Input Static Torque Kg-m lb-in	12.15 1055	17.8 1545	23.84 2070	34.48 2993	41.91 3639	47.38 4113	
Input Dynamic Torque kg-m lb-in	10.66 7925	16.71 1451	20.1 1745	31.93 2772	40.12 3483	45.51 3951	
Percentage of Full Load %	48%	76%	91%	145%	182%	207%	
Cycles	$4x10^5$	$5x10^5$	$1.4x10^6$	$3.8x10^6$	$3.2x10^6$	$2.6x10^6$	
Operating time (hour)	20	25	70	193	161	130	599
Condition of tooth Surface	Two Contact Bands	Bright Normal	Normal	Normal	Normal	Normal	

Table 3. Record of Noise Measurement for Double Circular Arc Gear Reducer
Unit dB(A)

	Measuring Point					
Load	1	2	3	4	Average	Background Noise
12.15 kg-m 1055 lb-in	68.5	68	67	66.5	67.5	
23.84 kg-m 2070 lb-in	64	64	64	64	64	53
34.48 kg-m 2993 lb-in	71	66.5	66.5	65.5	68.1	51
41.92 kg-m 3639 lb-in	73	68	68	57.4	66.6	56
47.38 kg-m 4113 lb-in	70.5	67.5	65.5	61	67.3	50

Note: The background noise modifications have been made for the data of each point in Table 4.

Table 4. Record of Vibration Measurement Units (μ m)

Vibration of double circular arc gear reducer				Vibration of involute gear reducer			
Load	Z	X	Y	Load	Z	X	Y
23.84 kgf-m 2070 lb-in	1.47	0.63	0.84	16.72 kgf-m 1452 lb-in	0.84	0.7	0.98
34.48 kgf-m 2993 lb-in	1.4	1.82	1.26	21.63 lgf-m 1878 lb-in	0.56	0.28	0.42
41.92 kgf-m 3639 lb-in	0.91	1.47	1.19	28.17 kgf-m 2445 lb-in	0.42	0.28	0.42
47.38 kgf-m	1.33	2.1	1.4				

Table 5. Loading State of Involute Gear Reducer

	Loading Number				Total
	1st	2nd	3rd	4th	
Static Torque kg-m lb-in	13.19 1145	16.72 1452	21.63 1878	28.17 2446	
Dynamic Torque kg-m lb-in	9.5 825	14.62 1269	18.75 1628	23.24 2018	
Percentage of full load	43%	66%	80%	106%	
Operating time (hour)	92	160	200	200	652
Cycles	$1.84x10^6$	$3.2x10^6$	$4x10^6$	$4x10^6$	
Condition of Tooth Surface	Smaller Contact Area	Bright Tooth face Little Wear	Some Surface Distress	Considerable Surface Distress	

Table 6. Record of Noise Measurement for Involute Gear Reducer Unit dB(A)

Load	Measuring Point				Average	Background Noise
	1st	2nd	3rd	4th		
16.72 kg-m 1406 lb-in	65	62	60	60	62.2	50
21.63 kg-m 1878 lb-in	64.5	61.5	60.5	60	62	48
28.17 kg-m 2446 lb-in	66	62	60.5	60	62.8	52

Note: The background noise modifications were made for the data of each point in Table 4.