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High Contact Ratio Gearing: A Technology Ready for Implementation?

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Charles D. Schultz, Beyta Gear Service

Abstract

Today's competitive industrial gear marketplace demands products with excellent reliability, high capacity, and low noise. Surface hardened ground tooth gearing predominates but the legacy tooth forms handicap further improvements in capacity and noise generation. Vehicle and aircraft equipment use tooth forms not found in the standard tables to achieve better performance at little or no increase in cost. This paper will propose adopting these high contact ratio forms to industrial use.

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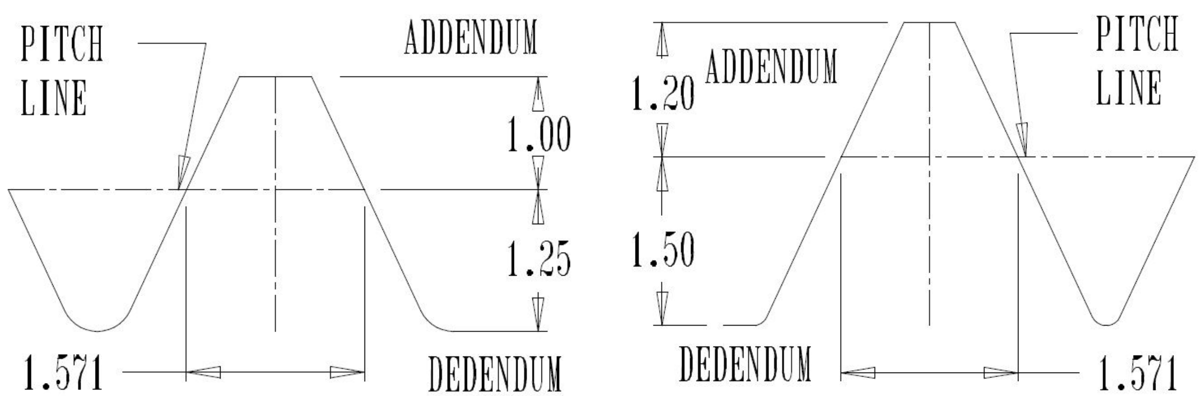
Discussion

I first became aware of deeper than standard tooth forms in 1979. The venerable company had been through tough times but its staff of engineers and designers came up with some creative solutions in the effort to remain competitive. When competitors started to shift to carburized gearing and invest in gear grinding equipment, the owners did not have the cash to follow suit. Some clever engineer decided to use teeth that were 20% deeper than standard and nitride them. The rating methods then in effect gave them competitive power densities with only the purchase of custom cutting tools.

The 1.2 addendum combined with the 25 degree pressure angle did not result in true high contact ratio geometry (see Figure 1). Poor tool life, especially when cutting hard pre-nitriding blanks, made for some production challenges. Coming from a through hardening background I was very skeptical but over time found the tooth form provided good results in the field. Replacing the special hobs wasn't possible in the reduced order volume of the early 1980s, however, and we did not use the 1.2 addendum system in new design standard products.

My next exposure to high contact ratio gearing came eleven years later during a tour of the Saturn automobile plant in Spring Hill, Tennessee. The Society of Automotive Engineers (SAE) organized the event and we were keen to see the compact, integrated gear manufacturing cell that had been set up to produce all the components needed for a front wheel drive transaxle. It was an impressive achievement in 1990 to begin with raw forgings at one end of the line and have complete carburized, hardened, and ground helical gears ready for assembly at the other end. General Motors spent plenty of money on the project and it challenged the best equipment builders in the world to participate.

The gear line included an automated inspection station after the gear grind operation. While watching the charting of parts in the cue, I noticed that the teeth were much deeper than "normal" but did not think to ask our guide a question about it. The equipment supplier gave out sample charts and when we debriefed back at our office we tried to run the geometry shown on it through our gear analysis software. The home brewed code "blew up" at the dimensions entered and when we dug into the error codes it was found to have exceeded the "allowable" profile contact ratio of 1.99. We didn't at first understand the significance of this limit in conventional gear design but after scouring our engineering library we came across a great paper by Leming [1] that explained things very well. Despite the many advantages of high contact ratio gearing that Leming pointed out, we put the concept aside and continued to design products with "standard" teeth.



Conventional 20 degree rack **1.2 addendum rack**

Figure 1. Deeper than standard tooth form

A couple years later, though, one of our salesmen asked us to help a potential customer resolve a noise problem with his equipment. Our firm had a well-deserved reputation as a supplier of high quality ground tooth gears and we went to work reviewing a consultant's telephone book thick report on the customer's "problem." Unfortunately, the solutions suggested were things we had tried before without much success and we told the salesman we did not think the project was worth pursuing. This salesman was a very persistent man and he refused to take no for an answer. Under the guise of giving the client a tour of our facility, he arranged for a couple of engineers to meet with my boss and me. We explained our dismal prognosis for quieting his gearbox and figured we were done with the matter. These engineers were just as persistent as our salesman and they knew we wouldn't be able to resist a well-argued challenge. Especially after they told us their project motto was "We won't fail because we didn't spend enough money."

During the brainstorming that followed the Saturn tour, the Leming article came up. While I went to retrieve the reference book with the Leming paper in it, my boss committed to me designing a set of high contact ratio gears in less than a week. There was, after all, a three day weekend coming up and there would be fewer distractions. Six days later we met again and reviewed the proposed design. We had no way of predicting the possible noise reduction but the geometry worked out and we were ready to make drawings. The customer started expediting delivery of prototypes before the review meeting was over. We thought perhaps two weeks after the hobs arrived, maybe eight to ten weeks total.

This was not acceptable and the customer promised to use his influence to get the hobs made more quickly. The next day, when the drawings were done, he called back to report that there could be no rush hob delivery. What other options were there? Jokingly reminding him of his project motto, we suggested wire cutting the parts. He didn't find the attempted humor funny and asked for blanks to be ready for his pick-up in two days. Said blanks were back to us three days later with Q9 quality teeth cut in them using tooth plots we provided. The sample gearbox was put on test two weeks later and the results were excellent. Noise reduction goals were easily met with no tooth modifications required.

Knowledgeable observers could not let go of the long thin teeth appearing to be so delicate. Surely those skinny teeth will break, they insisted. Upon the completion of the sound tests, the prototype gearbox was subjected to the same breakage test used many years earlier to approve the previous gearbox for production. It was still running flawlessly after completing the test three times. The conventional gearbox seldom survived extended testing. A modified version of the high contact ratio gearbox has now been in production for over 20 years.

Tooling budgets and production schedules prevented me from using high contact ratio tooth forms often while a gear company engineer. We managed to purchase a few HCR hobs for specific projects where there simply was not enough room for conventional gears to transmit the load but, regrettably, there was not the will to implement this technology in a widespread way. Now that I have my own consulting firm I hope to change that situation and assist clients in developing HCR geared products.

The history of high contact ratio gearing

The official "history" of high contact ratio gears begins with aircraft gearboxes in World War II. Leming's excellent summary of the development work on aircraft systems was published in 1977 but there is also some unofficial history dating back much further that bears study.

We take the "standard" involute tooth forms for granted as they were adopted long before any of today's working engineers were born. The 14-1/2 degree "full depth" involute was the first to gain official recognition in April of 1921, but even back then there was an effort to switch to 20 degrees, first at stub depth and shortly thereafter at full depth, to meet increasing load requirements for automobiles and trucks. A "composite" 14-1/2 degree system which combined an involute and cycloidal form into a single reference rack was also adopted in the 1920s, a recognition that not everyone was completely sold on the involute system either.

So where did the "standard" form come from? If you look at old photographs or drawings you will see a variety of tooth proportions, especially prior to the widespread use of hobbing and shaping machines in the late 1880s. Many gears had cast teeth and there is some evidence that the 14-1/2 degree system became popular in part because the sine of 14-1/2 degrees is 0.25 and that makes it easier to draw the tooth shape into the pattern than other pressure angles. A more plausible reason, based upon my limited foundry experience, is that 14-1/2 degree teeth have wider top lands which would be easier to maintain in the foundry conditions of that time.

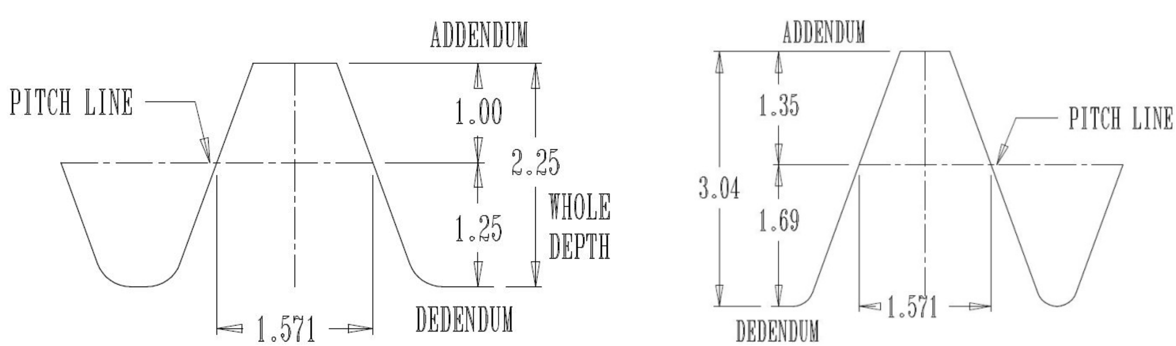
In research for this paper I purchased a reprint of the *American Machinist Gear Book.* [2] Originally published in 1915 (before AGMA was founded), this volume is a time capsule of our trade. Six different involute tooth systems are described as a prelude to discussing the need for a “standard” tooth form (see Table 1). Wilfred Lewis’ 1900 speech to the American Society of Mechanical Engineers (ASME) is quoted at length. When he started in gears in 1870 cycloidal teeth were predominant. By 1875 he was sold on the advantages of the involute system but he didn’t like the 14.5 and 15 degree systems proposed. He went with 20 degrees as “I did not at the time have the courage of my convictions that the obliquity should be 22.5 degrees or one-fourth of a right angle.” I mention this as evidence that there is nothing magic about the tooth forms we have settled on as “standard.” Using Lewis’ dates, we have a time line of involute teeth coming into common use in 1875, a committee being assigned to adopt a standard form in 1891 with ASME, AGMA being formed in 1914, and the 14.5 degree full depth tooth not being enshrined as standard until the 1921 AGMA Annual meeting. Even in 1921 there was enough debate so that the 20 degree stub, composite cycloidal/involute rack, and 20 degree full depth form were put “on track” for later standardization.

It is reasonably safe to say that the 14.5 degree form was not selected for its dynamic characteristics as the 1921 debate recognized the more favorable sliding characteristics of the 20 degree stub system along with its purported greater strength. I say “purported” based upon some instances I observed many years later where shaker screen gears were actually found to resist tooth breakage better at 14-1/2 degrees than even 25 degrees. This puzzled us until we discovered the profile contact ratio was 2.47 with the legacy tooth form and only 1.63 with the supposedly stronger 25 degree tooth. The same part with 20 degree full depth teeth had a 1.93 profile contact ratio and it too suffered tooth breakage in the field. This situation points out the need to avoid single tooth contact entirely when designing HCR sets; the profile contact ratio has to remain over 2.00 at all times regardless of tip relief or center distance fluctuation.

Many pressure angle and tooth depth systems were in use prior to “standardization” and they continued to be popular long after the 1920’s. None had an addendum that exceeded the familiar 1/transverse diametrical pitch until Buckingham [3] (Section 2, *Spur and Internal Gears)* proposed a 1.35/NDP system for instrument gears (see Figure 2). I confess to using this book for many years and not noticing this gear tooth system until I started researching this paper. Buckingham does not discuss profile ratio in his presentation despite developing the rack offsets needed to use the tooth form on spur pinions down to 5 teeth.

Table 1. Existing tooth “standards” in 1915, per *American Machinist Gear Book* (pp. 23-24)

	Pressure angle	Addendum	Dedendum	Whole depth
Brown & Sharpe	14.5	1/p	1.157/p	2.157/p
Grant	15	1/p	1.157/p	2.157/p
Sellers	20	1/p	1.157/p	2.157/p
Hunt	14.5	0.7857/p	0.9424/p	1.7278/p
Logue/Nuttall	20	0.7857/p	0.9424/p	1.7278/p
Fellows stub*	20	1/p’	1.157/p’	2.157/p’
- Tooth thickness based on p; tooth height based on p’. - Examples: 2/2.5, 2.5/3, 3/4, 4/5, 5/7, 7/9, 8/10, 10/12, 12/14, 14/18.				



Conventional 20 degree rack diagram Buckingham 1.35 addendum rack diagram

Figure 2. High contact ratio tooth form

This is not to say that high contact ratio gears were not used prior to 1935. One example of very non-standard tooth proportions that I am personally familiar with dates to the 1895 vintage Hulet unloading machines. These revolutionary devices caused an amazing reduction in the cost of unloading bulk products from the holes of ships on the Great Lakes and are considered national landmarks in Cleveland, Ohio and Superior, Wisconsin. The drive mechanism used “finger gears” to allow for a big change in center distance (on the order of 1 inch). Finger gears (see Figure 4) were so named because they looked like fingers. The pressure angle was very low, around 8 degrees, but the whole depth was on the order of 5 inches divided by the nominal DP. We were contracted to make spare pinions using our 1916 vintage gear milling machine. As I recall, the tooth space was so deep and narrow we had to use three different milling cutters get the shape and, because of accuracy limitations of the technology, hand file the transitions to get relatively smooth operation.

Most of the manufacturing techniques currently in use were available 100 years ago. The machines were far less accurate and they were a great deal slower. Metallurgy and heat treating were not as sophisticated; bearings were of much lower capacity and quality. Every aspect of machinery was slower and our predecessors, being very practical people, reserved gear grinding for applications where it was the only way to get the gearbox to work. The 14-1/2 degree full depth form was still adequate for most applications in 1921 but designers could see that the 20 degree form, first in stub depth and later in full depth, offered advantages for the future.

My purpose in bringing this topic into the discussion of high contact ratio teeth is simply this: The old answers were based on old conditions. We have different conditions in effect today. Many of the old technology and cost limitations are no longer in effect. We are under great commercial pressure to produce lighter, more compact, longer lasting gearboxes at lower prices. The design rules have to change to help us respond to those commercial pressures.

Design concerns with HCR teeth

Since the publication of Leming’s paper, high contact ratio (HCR) gears have been used in many aircraft, defense, and vehicle applications. They have yet to be featured in “catalog” gearboxes despite the following advantages:

- Increased durability rating
- Increased strength rating
- Reduced noise levels

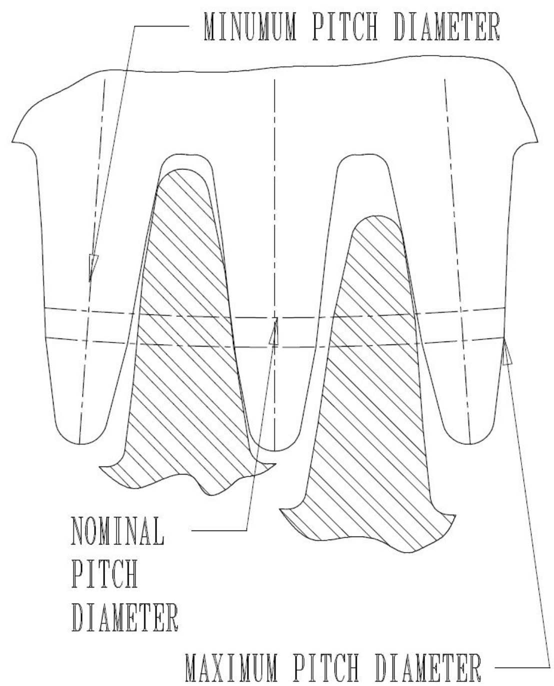


Figure 3. Hulet unloader finger gears

These advantages, while noteworthy, have been overshadowed by concerns about susceptibility to scoring or other lubrication failures, lower efficiency, narrow top lands, limited bearing capacity, gearbox thermal limitations, tooling costs, and uncertainty over rating methods. During these past decades many papers have been presented on these concerns as our aircraft and vehicle designing colleagues investigated the best ways to use the immerging technology. I claim no great breakthroughs in this paper but hope to alleviate a few fears and suggest a path forward.

The most difficult advantage to quantify for HCR designs is reduced noise level. In every application of HCR gearing that I know of the noise level was lower than the conventional gearing it replaced. While mathematical models have been developed to determine optimum tooth modifications for conventional gears, those models require specific information on the load and speed for which noise reduction is needed. Catalog products are sold “off the shelf” with only limited load and speed information. A recent paper on the use of HCR timing gears in diesel truck engines [4] revealed that the best noise performance was obtained with gears having little or no profile modification. The worst performers had modifications closer to what conventional math models suggested was “optimum.” My own experience with un-modified HCR profiles leads me to believe HCR gearing can be successfully used in catalog gearboxes with no tip or root relief at all.

With regard to the durability rating of HCR gears, the theoretical basis of current AGMA and ISO contact stress formulas has no restrictions on profile contact ratio. The increased capacity of HCR teeth is a matter of tooth curvature and the length of the line of contact. Depending upon the addendum factor chosen for the HCR tooth form, durability ratings can increase from 25 to 50% over similar sized conventional gears. Lab testing has confirmed these results [5].

Our current tooth bending strength models are based upon single tooth contact. True HCR designs never see single tooth loading so a new stress calculation formula will ultimately be needed to accurately predict the success of any HCR tooth form. Photo elastic modeling and finite element analysis results indicate that HCR teeth experience between 57 and 63% of the bending load of conventional gearing. Further testing will be needed before an HCR bending strength formula can be adopted.

Math modeling HCR gears

For the purposes of this paper I have selected two different sizes cataloged parallel shaft double reduction speed reducers for study. Since specific design details are proprietary, I began by designing conventional gear, normal contact ratio (NCR) sets that would fit within the housing envelope and then selecting suitable taper roller bearings. These conventional 25 degree pressure angle helical sets were then rated for durability and strength to confirm that they were capable of the published catalog ratings. The catalog ratings and simulated gear geometry were used to calculate L-10 gearing life using the advanced method (a23 factor).

The next step was to design HCR gear sets for the same conditions and repeat the durability and strength calculations before revisiting the bearing life issue. Durability was calculated using the AGMA 2001 method; strength was calculated using the standard method but the result was divided by 0.60 to reflect the load sharing reported in FEA modeling. As there is no “standard” HCR tooth form I elected to use the 1.35 addendum 20 degree NPA system Professor Buckingham proposed for instrument gearing. Occasional minor warning notes were received from the rating software for top lands less than 0.250/NDP but the rating process was otherwise unimpeded. Narrow top lands are thought to contribute to tooth bending failures; the same warnings were received on some NCR 25 degree pressure angle sets.

While proposals have been advanced to achieve profile contact ratios of 1.95 or more using standard 20 degree full depth tooling [6], I chose to study only deeper than standard depth tooth forms. The use of standard depth tools on HCR gears results in reduced operating pressure angles and increased risk of undercutting without the increased durability rating offered by the deeper tooth form. Catalog ratings are determined by the lowest capacity in a number of categories. Back in the through hardened days it was expected that products would be durability limited and that strength ratings would generally be 40 to 50% higher. When we moved to carburized and hardened gearing we found that the durability and strength ratings both came into play in establishing catalog ratings.

The use of standard depth tooling to achieve HCR profile overlaps would return us to durability limited catalog ratings. Overall ratings would probably not increase at all. Contrast this with the move to deeper than standard teeth where durability capacity will increase by 25 to 50% and strength ratings may double. Commercial success comes with high quality products at lowest prices; high power density contributes to lower prices as you are more likely to be able to meet a specific application with a "one size smaller" gearbox than a competitor.

Tables 2 through 5 show the results of the two unit NCR/HCR rating comparison. HCR designs achieved a durability rating increase of 28 to 29%. HCR strength ratings were 44 to 48% more than comparable NCR designs. Greater improvements may be possible with more flexibility in the choice of center distance combinations and stage ratios. These particular examples were chosen to illustrate the potential for HCR redesigns of existing products using existing housing dimensions.

Many existing product lines are also bearing life limited; the 25 degree normal pressure angles needed to obtain high bending strengths also increase the forces on the bearings. Space limitations and bearing availability prevent squeezing in more bearing capacity. The lower pressure angles used in the HCR designs have lower bearing forces but the packaging problem may prevent utilization of increased rating capacity. Allowable "bearing horsepower" for each of the units studied are shown on Tables 6 through 9. With the space available for bearings in the current design units, I was not able to obtain a 10,000 hour L-10 on every bearing with the published catalog ratings. Since few gearboxes are sold at a unity service factor this is not a surprise.

Converting existing gearbox designs to HCR will reduce noise levels and provide additional service factor. To best leverage the technology, however, more flexibility in center distance sequences and ratio combinations will be needed. This is not unprecedented. A review of parallel shaft gearbox catalogs shows that pre-1964 designs had far different proportions than more recent designs. The first stage center distance in those through hardened units is typically 50 to 62 percent of the second stage. The low speed gear ratio in those units may be as high as 6.5:1. These are a reflection of the rating methods in effect at the time they were designed. Up until 1964, for example, the durability rating was calculated based upon pinion pitch diameter and pinion rotational speed. This, along with the favorable treatment of allowable stress for second and third reductions, encouraged higher ratios on the output set.

When the "modern" rating method was adopted via AGMA 218 in the 1980s, the durability rating formula changed to the pinion pitch diameter SQUARED and the favorable treatment of second and third reductions went away. This change in rating method is reflected in the design of newer parallel shaft units. The first stage center distances are now typically 70 to 80% of the second stage. Output stage gear ratios seldom exceed 5:1. Just as the adoption of carburized and ground gearing motivated that shift, HCR designs may also require a different approach to these fundamental design parameters.

With regard to the lubrication concerns with HCR gears, scoring and wear probabilities were calculated for the modeled gears using commercial software. Unfortunately, the program wouldn't accept gearing with profile contact ratios over 2.00 so the outside diameters of the HCR gears was reduced to obtain a 1.99. With the surface finish expected for form ground gears (22 AA) and required lubricant conditions (ISO 320EP at 160 F bulk temperature) all sets had scoring and wear probabilities of less than 5%.

Efficiency testing, in conjunction with thermal rating development, would be necessary to determine whether HCR gearing has any disadvantage compared to similar sized NCR gearing. A review of the factors involved with operating efficiency and thermal limitation shows that the longer line of action and slightly larger outside diameters of the HCR designs could increase power loss. On the other hand, the higher power density of HCR gearing would make the drives smaller in size and potentially make the overall efficiency equal. The author is not privy to the test results of automotive gearbox builders but doubts they would have moved to HCR designs if efficiency were a problem.

The way forward

The advantages of HCR gear designs are ripe for commercial adoption. Tougher noise restrictions are inevitable and HCR technology has amply demonstrated its ability to reduce noise levels in vehicles. The opportunity to increase power density, be it for overall commercial advantage or just to raise ratings in specific situations, at only a slight increase in material cost is very attractive in today's competitive market.

Early adopters of any technological change have to temper enthusiasm with common sense. A well thought out test program will be needed to verify the rating advantages and validate the thermal capacity of the products. Theoretical work is needed to support a new high contact ratio bending strength rating method along with laboratory testing of HCR sets under standardized conditions.

Table 2. Conventional gearing (2H155 gearbox)

UNIT RATIO>	6.3076	6.8421	8.1092	8.7579	9.9522		10.7094	12.7973	13.8109	16.0105	17.2540		
	single helical	single helical	single helical	single helical	single helical		single helical	single helical	single helical	single helical	single helical		single helical
Set #	155H1	155H2	155H3	155H4	155H5	<LOCATION	155H6	155H7	155H8	155H9	155H10	<LOCATION	155L
Catalog HP	239	216	187	169	154	Catalog HP	138	120	108	96	87	Catalog HP	various
CENTERS (mm)	109	109	109	109	109	CENTERS (mm)	109	109	109	109	109	CENTERS (mm)	155
CENTERS (in)	4.291	4.291	4.291	4.291	4.291	CENTERS (in)	4.291	4.291	4.291	4.291	4.291	CENTERS (in)	6.102
GEAR TEETH	59	60	64	64	64	GEAR TEETH	72	101	109	117	116	GEAR TEETH	65
PINION TEETH	32	30	27	25	22	PINION TEETH	23	27	27	25	23	PINION TEETH	19
RATIO	1.8438	2.0000	2.3704	2.5600	2.9091	RATIO	3.1304	3.7407	4.0370	4.6800	5.0435	RATIO	3.4211
FACE WIDTH	1.969	1.969	1.969	1.969	1.969	FACE WIDTH	1.969	1.969	1.969	1.969	1.969	FACE WIDTH	3.543
NDP	11.2889	11.28890	11.2889	11.2889	11.2889	NDP	12.7	16.93330	16.9333	18.1429	16.9333	NDP	7.25714
NPA	25	25	25	25	25	NPA	25	25	25	25	25	NPA	25
HELIX ANGLE	20.0789	21.7360	20.0790	23.2809	27.4250	HELIX ANGLE	29.3596	28.2690	20.6455	24.2270	16.9766	HELIX ANGLE	18.4875
TDP	10.6028	10.4862	10.6028	10.3697	10.0202	TDP	11.0688	14.9138	15.8459	16.5450	16.1954	TDP	6.8826
PINION PD	3.0181	2.8609	2.5465	2.4109	2.1956	PINION PD	2.0779	1.8104	1.7039	1.5110	1.4202	PINION PD	2.7606
GEAR PD	5.5646	5.7218	6.0362	6.1718	6.3871	GEAR PD	6.5048	6.7723	6.8788	7.0716	7.1625	GEAR PD	9.4441
Pinion X1	0.1500	0.1650	0.1900	0.2000	0.2000	Pinion X1	0.2000	0.2000	0.2500	0.2500	0.2650	Pinion X1	0.3000
PINION OD	3.222	3.067	2.757	2.624	2.408	PINION OD	2.267	1.952	1.852	1.649	1.570	PINION OD	3.119
GEAR OD	5.715	5.870	6.180	6.314	6.529	GEAR OD	6.631	6.867	6.967	7.154	7.249	GEAR OD	9.637
Mp	1.38	1.35	1.37	1.32	1.25	Mp	1.23	1.26	1.36	1.31	1.39	Mp	1.34
Mf	2.43	2.62	2.43	2.80	3.26	Mf	3.90	5.03	3.74	4.67	3.10	Mf	2.02
PINION HT	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	GEAR HT	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	GEAR HT	58-62 Rc
GEAR HT	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	PINION HT	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	PINION HT	58-62 Rc
AGMA Q#	11	11	11	11	11	AGMA Q#	11	11	11	11	11	AGMA Q#	11
Cm	1.08	1.08	1.08	1.08	1.08	Cm	1.08	1.08	1.08	1.08	1.08	Cm	1.15
PINION RPM	1800	1800	1800	1800	1800	PINION RPM	1800	1800	1800	1800	1800	PINION RPM	various
PINION DUR.HP	308	281	241	224	197	PINION DUR.HP	180	147	130	**105**	98	PINION DUR.HP	
GEAR DUR.HP	317	291	251	234	207	GEAR DUR.HP	190	156	139	113	105	GEAR DUR.HP	
PINION STR.HP	288	277	248	238	213	PINION STR.HP	184	**126**	**117**	**96**	**97**	PINION STR.HP	
GEAR STR.HP	**284**	**274**	247	237	213	GEAR STR.HP	197	129	118	99	100	GEAR STR.HP	
LS Pinion RPM	976	900	759	703	619	LS Pinion RPM	575	481	446	385	357	LS Pinion RPM	
LS Pinion DurHP	**249**	**232**	**197**	**184**	**163**	LS Pinion DurHP	**152**	**129**	**120**	105	**98**	LS Pinion DurHP	
LS Gear DurHP	263	246	208	194	173	LS Gear DurHP	161	137	127	111	103	LS Gear DurHP	
LS Pinion Str HP	313	292	246	229	203	LS Pinion Str HP	189	160	148	129	120	LS Pinion Str HP	
LS Gear Str HP	303	282	**238**	**222**	**196**	LS Gear Str HP	**183**	154	144	124	116	LS Gear Str HP	
Unit Dur. HP	249	232	197	184	163	Unit Dur. HP	152	129	120	105	98	Unit Dur. HP	
Unit Str. HP	284	274	238	222	196	Unit Str. HP	183	126	117	96	97	Unit Str. HP	
Dur. SF to Cat	1.04	1.07	1.05	1.09	1.06	Dur. SF to Cat	1.10	1.08	1.11	1.09	1.13	Dur. SF to Cat	
Str.SF to Cat	1.19	1.27	1.27	1.31	1.27	Str.SF to Cat	1.33	1.05	1.08	1.00	1.11	Str.SF to Cat	
Thermal HP	84	84	84	84	77	Thermal HP	77	77	77	71	71	Thermal HP	
1 fan	139	139	139	139	127	1 fan	127	127	127	116	116	1 fan	
2 fans	210	210	210	210	193	2 fans	193	193	193	176	176	2 fans	

Table 3. HCR gearing, 1.35 addendum system (2H155 gearbox)

UNIT RATIO>	6.3076	6.8421	8.1092	8.7296	10.0000		10.7519	12.8014	13.8109	16.0526	17.2540			
	single helical	single helical	single helical	single helical	single helical		single helical	single helical	single helical	single helical	single helical		single helical	
Set #	155H1	155H2	155H3	155H4	155H5	<LOCATION	155H6	155H7	155H8	155H9	155H10	<LOCATION	155L	
Catalog HP	239	216	187	169	154	Catalog HP	138	120	108	96	87	Catalog HP	various	
CENTERS (mm)	109	109	109	109	109	CENTERS (mm)	109	109	109	109	109	CENTERS (mm)	155	
CENTERS (in)	4.291	4.291	4.291	4.291	4.291	CENTERS (in)	4.291	4.291	4.291	4.291	4.291	CENTERS (in)	6.102	
GEAR TEETH	59	60	64	74	76	GEAR TEETH	88	116	109	122	116	GEAR TEETH	65	
PINION TEETH	32	30	27	29	26	PINION TEETH	28	31	27	26	23	PINION TEETH	19	
RATIO	1.8438	2.0000	2.3704	2.5517	2.9231	RATIO	3.1429	3.7419	4.0370	4.6923	5.0435	RATIO	3.4211	
FACE WIDTH	1.969	1.969	1.969	1.969	1.969	FACE WIDTH	1.969	1.969	1.969	1.969	1.969	FACE WIDTH	3.543	
NDP	11.2889	11.28890	11.2889	12.7	12.7	NDP	14.5143	18.00000	16.9333	18	16.9333	NDP	7.25714	
NPA	20	20	20	20	20	NPA	20	20	20	20	20	NPA	20	
HELIX ANGLE	20.0789	21.7360	20.0790	19.0991	20.6455	HELIX ANGLE	21.3787	17.9122	20.6455	16.6642	16.9766	HELIX ANGLE	18.4875	
TDP	10.6028	10.4862	10.6028	12.0009	11.8844	TDP	13.5156	17.1275	15.8459	17.2440	16.1954	TDP	6.8826	
PINION PD	3.0181	2.8609	2.5465	2.4165	2.1877	PINION PD	2.0717	1.8100	1.7039	1.5078	1.4202	PINION PD	2.7606	
GEAR PD	5.5646	5.7218	6.0362	6.1662	6.3949	GEAR PD	6.5110	6.7727	6.8788	7.0749	7.1625	GEAR PD	9.4441	
Pinion X1	0.1500	0.1650	0.1900	0.1900	0.2200	Pinion X1	0.2200	0.2400	0.2500	0.2600	0.2650	Pinion X1	0.3000	
PINION OD	3.285	3.129	2.819	2.666	2.435	PINION OD	2.288	1.987	1.893	1.687	1.611	PINION OD	3.119	
GEAR OD	5.778	5.932	6.242	6.356	6.573	GEAR OD	6.667	6.896	7.009	7.196	7.291	GEAR OD	9.637	
Mp	2.05	2.01	2.02	2.12	2.01	Mp	2.02	2.11	2.03	2.10	2.06	Mp	1.34	
Mf	2.43	2.62	2.43	2.60	2.81	Mf	3.32	3.47	3.74	3.24	3.10	Mf	2.02	
PINION HT	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	GEAR HT	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	GEAR HT	58-62 Rc	
GEAR HT	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	PINION HT	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	PINION HT	58-62 Rc	
AGMA Q#	11	11	11	11	11	AGMA Q#	11	11	11	11	11	AGMA Q#	11	
Cm	1.08	1.08	1.08	1.08	1.08	Cm	1.08	1.08	1.08	1.08	1.08	Cm	1.15	
PINION RPM	1800	1800	1800	1800	1800	PINION RPM	1800	1800	1800	1800	1800	PINION RPM	various	
PINION DUR.HP	410	382	322	305	258	PINION DUR.HP	239	192	174	142	129	PINION DUR.HP		
GEAR DUR.HP	422	394	335	319	271	GEAR DUR.HP	251	204	186	153	139	GEAR DUR.HP		
PINION STR.HP	460	435	379	329	293	PINION STR.HP	**250**	**181**	**177**	**145**	**140**	PINION STR.HP		
GEAR STR.HP	473	449	401	352	309	GEAR STR.HP	271	198	196	164	162	GEAR STR.HP		
LS Pinion RPM	976	900	759	705	616	LS Pinion RPM	573	481	446	384	357	LS Pinion RPM		
LS Pinion DurHP	**320**	**299**	**253**	**236**	**210**	LS Pinion DurHP	**196**	**166**	**155**	**135**	**126**	LS Pinion DurHP		
LS Gear DurHP	338	316	268	250	222	LS Gear DurHP	207	176	164	143	133	LS Gear DurHP		
LS Pinion Str HP	**408**	**400**	**338**	**315**	**279**	LS Pinion Str HP	259	219	204	176	164	LS Pinion Str HP		
LS Gear Str HP	440	431	364	339	300	LS Gear Str HP	279	236	219	190	177	LS Gear Str HP		
Unit Dur. HP	320	299	253	236	210	Unit Dur. HP	196	166	155	135	126	Unit Dur. HP		
Unit Str. HP	408	400	338	315	279	Unit Str. HP	250	181	177	145	140	Unit Str. HP		
Dur. SF to Cat	1.34	1.38	1.35	1.40	1.36	Dur. SF to Cat	1.42	1.38	1.44	1.41	1.45	Dur. SF to Cat		
Str.SF to Cat	1.71	1.85	1.81	1.86	1.81	Str.SF to Cat	1.81	1.51	1.64	1.51	1.61	Str.SF to Cat		
NCR dur	249	232	197	184	163	NCR dur	152	129	120	105	98	NCR dur		
NCR Str	284	274	238	222	196	NCR Str	183	126	117	96	97	NCR Str		
dur increase	1.29	1.29	1.28	1.28	1.29	dur increase	1.29	1.29	1.29	1.29	1.29	dur increase	1.29	average
strength increase	1.44	1.46	1.42	1.42	1.42	strength increase	1.37	1.43	1.51	1.51	1.45	strength increase	1.44	average

Table 4. Conventional gearing (2H330 gearbox)

UNIT RATIO>	6.4316	7.0955	8.1579	8.9961	9.8966		10.9211	12.7918	14.0789	15.5373	17.1053		
	single helical	single helical	single helical	single helical	single helical		single helical	single helical	single helical	single helical	single helical		single helical
Set #	330H1	330H2	330H3	330H4	330H5	<LOCATION	330H6	330H7	330H8	330H9	330H10	<LOCATION	330L
Catalog HP	1,910	1,810	1,650	1,440	1,370	Catalog HP	1,190	1,070	934	889	770	Catalog HP	various
CENTERS (mm)	226	226	226	226	226	CENTERS (mm)	226	226	226	226	226	CENTERS (mm)	330
CENTERS (in)	8.898	8.898	8.898	8.898	8.898	CENTERS (in)	8.898	8.898	8.898	8.898	8.898	CENTERS (in)	12.992
GEAR TEETH	47	56	62	71	81	GEAR TEETH	83	86	107	109	95	GEAR TEETH	65
PINION TEETH	25	27	26	27	28	PINION TEETH	26	23	26	24	19	PINION TEETH	19
RATIO	1.8800	2.0741	2.3846	2.6296	2.8929	RATIO	3.1923	3.7391	4.1154	4.5417	5.0000	RATIO	3.4211
FACE WIDTH	4.000	4.000	4.000	4.000	4.000	FACE WIDTH	4.000	4.000	4.000	4.000	4.000	FACE WIDTH	5.846
NDP	4.2333	5.08000	5.08	6	6.35	NDP	6.35	6.35000	7.8154	7.8154	6.7733	NDP	3.3867
NPA	25	25	25	25	25	NPA	25	25	25	25	25	NPA	25
HELIX ANGLE	17.1078	23.3441	13.2320	23.3867	15.2904	HELIX ANGLE	15.2904	15.2904	16.9998	16.9998	18.9502	HELIX ANGLE	17.3414
TDP	4.0460	4.6642	4.9451	5.5071	6.1252	TDP	6.1252	6.1252	7.4739	7.4739	6.4062	TDP	3.2327
PINION PD	6.1789	5.7888	5.2577	4.9028	4.5713	PINION PD	4.2447	3.7550	3.4788	3.2112	2.9659	PINION PD	5.8774
GEAR PD	11.6164	12.0065	12.5376	12.8925	13.2240	GEAR PD	13.5505	14.0403	14.3165	14.5841	14.8294	GEAR PD	20.1069
Pinion X1	0.1500	0.1750	0.2000	0.2500	0.2700	Pinion X1	0.3000	0.3250	0.3600	0.3750	0.3000	Pinion X1	0.2400
PINION OD	6.722	6.251	5.730	5.319	4.971	PINION OD	4.654	4.172	3.827	3.563	3.350	PINION OD	6.610
GEAR OD	12.018	12.331	12.853	13.142	13.454	GEAR OD	13.771	14.253	14.480	14.744	15.036	GEAR OD	20.556
Mp	1.39	1.32	1.43	1.32	1.42	Mp	1.41	1.39	1.39	1.37	1.34	Mp	1.36
Mf	1.59	2.56	1.48	3.03	2.13	Mf	3.13	2.13	2.91	2.91	2.80	Mf	1.88
PINION HT	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	GEAR HT	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	GEAR HT	58-62 Rc
GEAR HT	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	PINION HT	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	PINION HT	58-62 Rc
AGMA Q#	11	11	11	11	11	AGMA Q#	11	11	11	11	11	AGMA Q#	11
Cm	1.19	1.19	1.19	1.19	1.19	Cm	1.19	1.19	1.19	1.19	1.19	Cm	1.23
PINION RPM	1800	1800	1800	1800	1800	PINION RPM	1800	1800	1800	1800	1800	PINION RPM	various
PINION DUR.HP	2,165	2,102	1,750	1,749	1,557	PINION DUR.HP	1,389	1,142	1,014	888	750	PINION DUR.HP	
GEAR DUR.HP	2,229	2,174	1,822	1,828	1,635	GEAR DUR.HP	1,465	1,214	1,083	952	808	GEAR DUR.HP	
PINION STR.HP	2,527	2,175	1,821	1,693	1,453	PINION STR.HP	1,352	1,193	934	861	880	PINION STR.HP	
GEAR STR.HP	**2,488**	**2,139**	**1,793**	**1,644**	**1,410**	GEAR STR.HP	**1,302**	**1,148**	897	825	890	GEAR STR.HP	
LS Pinion RPM	957	868	755	685	622	LS Pinion RPM	564	481	437	396	360	LS Pinion RPM	
LS Pinion DurHP	**2068**	**1889**	**1661**	**1518**	**1390**	LS Pinion DurHP	**1266**	**1097**	**1004**	916	831	LS Pinion DurHP	
LS Gear DurHP	2189	1999	1758	1607	1471	LS Gear DurHP	1340	1161	1062	969	879	LS Gear DurHP	
LS Pinion Str HP	2578	2348	2057	1875	1712	LS Pinion Str HP	1555	1341	1224	1114	1007	LS Pinion Str HP	
LS Gear Str HP	2599	2367	**2074**	**1890**	**1726**	LS Gear Str HP	**1567**	1352	1234	1123	1016	LS Gear Str HP	
Unit Dur. HP	2068	1889	1661	1518	1390	Unit Dur. HP	1266	1097	1004	888	750	Unit Dur. HP	
Unit Str. HP	2488	2139	1793	1644	1410	Unit Str. HP	1302	1148	897	825	831	Unit Str. HP	
Dur. SF to Cat	1.08	1.04	1.01	1.05	1.01	Dur. SF to Cat	1.06	1.03	1.07	1.00	0.97	Dur. SF to Cat	
Str.SF to Cat	1.30	1.18	1.09	1.14	1.03	Str.SF to Cat	1.09	1.07	0.96	0.93	1.08	Str.SF to Cat	
Thermal HP	314	314	314	314	309	Thermal HP	309	309	309	293	293	Thermal HP	
1 fan	518	518	518	518	510	1 fan	510	510	510	484	484	1 fan	
2 fans	784	784	784	784	773	2 fans	773	773	773	733	733	2 fans	

Table 5. HCR gearing, 1.35 addendum system (2H330 gearbox)

UNIT RATIO>	6.4091	7.0381	8.1575	8.9646	9.8620		10.8829	12.7470	14.0297	15.4830	17.2004			
	single helical	single helical	single helical	single helical	single helical		single helical	single helical	single helical	single helical	single helical		single helical	
Set #	330H1	330H2	330H3	330H4	330H5	<LOCATION	330H6	330H7	330H8	330H9	330H10	<LOCATION	330L	
Catalog HP	1,910	1,810	1,650	1,440	1,370	Catalog HP	1,190	1,070	934	889	770	Catalog HP	various	
CENTERS (mm)	226	226	226	226	226	CENTERS (mm)	226	226	226	226	226	CENTERS (mm)	330	
CENTERS (in)	8.898	8.898	8.898	8.898	8.898	CENTERS (in)	8.898	8.898	8.898	8.898	8.898	CENTERS (in)	12.992	
GEAR TEETH	47	64	67	71	81	GEAR TEETH	83	86	107	109	111	GEAR TEETH	75	
PINION TEETH	25	31	28	27	28	PINION TEETH	26	23	26	24	22	PINION TEETH	22	
RATIO	1.8800	2.0645	2.3929	2.6296	2.8929	RATIO	3.1923	3.7391	4.1154	4.5417	5.0455	RATIO	3.4091	
FACE WIDTH	4.000	4.000	4.000	4.000	4.000	FACE WIDTH	4.000	4.000	4.000	4.000	4.000	FACE WIDTH	5.846	
NDP	4.2333	5.64440	5.6444	5.6444	6.35	NDP	6.35	6.35000	7.8154	7.8154	7.8154	NDP	3.3867	
NPA	20	20	20	20	20	NPA	20	20	20	20	20	NPA	20	
HELIX ANGLE	17.1078	18.9509	18.9509	12.6661	15.2904	HELIX ANGLE	15.2904	15.2904	16.9998	16.9998	16.9998	HELIX ANGLE	17.1624	
TDP	4.0460	5.3385	5.3385	5.5071	6.1252	TDP	6.1252	6.1252	7.4739	7.4739	7.4739	TDP	3.7330	
PINION PD	6.1789	5.8069	5.2449	4.9028	4.5713	PINION PD	4.2447	3.7550	3.4788	3.2112	2.9436	PINION PD	5.8933	
GEAR PD	11.6164	11.9884	12.5504	12.8925	13.2240	GEAR PD	13.5505	14.0403	14.3165	14.5841	14.8517	GEAR PD	20.0909	
Pinion X1	0.1500	0.1550	0.2200	0.2400	0.2600	Pinion X1	0.2900	0.3000	0.2650	0.2900	0.3000	Pinion X1	0.2850	
PINION OD	6.888	6.340	5.801	5.466	5.078	PINION OD	4.761	4.274	3.892	3.631	3.366	PINION OD	6.729	
GEAR OD	12.183	12.412	12.951	13.286	13.567	GEAR OD	13.884	14.371	14.594	14.855	15.120	GEAR OD	20.637	
Mp	2.03	2.06	2.05	2.13	2.11	Mp	2.09	2.06	2.08	2.06	2.04	Mp	2.02	
Mf	1.59	2.33	2.33	1.58	2.13	Mf	2.13	2.13	2.91	2.91	2.91	Mf	2.15	
PINION HT	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	GEAR HT	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	GEAR HT	58-62 Rc	
GEAR HT	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	PINION HT	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	58-62 Rc	PINION HT	58-62 Rc	
AGMA Q#	11	11	11	11	11	AGMA Q#	11	11	11	11	11	AGMA Q#	11	
Cm	1.19	1.19	1.19	1.19	1.19	Cm	1.19	1.19	1.19	1.19	1.19	Cm	1.23	
PINION RPM	1800	1800	1800	1800	1800	PINION RPM	1800	1800	1800	1800	1800	PINION RPM	various	
PINION DUR.HP	3,008	2,841	2,473	2,195	2,040	PINION DUR.HP	1,817	1,497	**1,305**	**1,150**	**893**	PINION DUR.HP		
GEAR DUR.HP	3,097	2,938	2,574	2,295	2,132	GEAR DUR.HP	1,917	1,591	1,392	1,233	962	GEAR DUR.HP		
PINION STR.HP	4,056	3,214	2,851	2,518	**2,222**	PINION STR.HP	**2,048**	1,788	**1,371**	**1,254**	**1010**	PINION STR.HP		
GEAR STR.HP	4,246	3,373	2,965	2,649	2,339	GEAR STR.HP	2,158	1,909	1,525	1,402	1149	GEAR STR.HP		
LS Pinion RPM	957	872	752	685	622	LS Pinion RPM	564	481	437	396	357	LS Pinion RPM		
LS Pinion DurHP	**2786**	**2557**	**2232**	**2047**	**1874**	LS Pinion DurHP	**1711**	**1479**	1353	1235	1120	LS Pinion DurHP		
LS Gear DurHP	2948	2705	2362	2165	1983	LS Gear DurHP	1811	1564	1432	1306	1185	LS Gear DurHP		
LS Pinion Str HP	**3400**	**3112**	**2706**	**2474**	2260	LS Pinion Str HP	2058	**1770**	1615	1470	1330	LS Pinion Str HP		
LS Gear Str HP	3674	3363	2924	2673	2442	LS Gear Str HP	2224	1912	1745	1588	1437	LS Gear Str HP		
Unit Dur. HP	2786	2557	2232	2047	1874	Unit Dur. HP	1711	1488	1305	1150	893	Unit Dur. HP		
Unit Str. HP	3400	3112	2706	2474	2222	Unit Str. HP	2048	1770	1371	1254	1010	Unit Str. HP		
Dur. SF to Cat	1.46	1.41	1.35	1.42	1.37	Dur. SF to Cat	1.44	1.39	1.40	1.29	1.16	Dur. SF to Cat		
Str.SF to Cat	1.78	1.72	1.64	1.72	1.62	Str.SF to Cat	1.72	1.65	1.47	1.41	1.31	Str.SF to Cat		
NCR Dur HP	2068	1889	1661	1518	1390	Unit Dur. HP	1266	1097	1004	888	750	Unit Dur. HP		
NCR Str HP	2488	2139	1793	1644	1410	Unit Str. HP	1302	1148	897	825	831	Unit Str. HP		
dur increase	1.35	1.35	1.34	1.35	1.35	dur increase	1.35	1.36	1.30	1.30	1.19	dur increase	1.32	average
strength increase	1.37	1.46	1.51	1.50	1.58	strength increase	1.57	1.54	1.53	1.52	1.22	strength increase	1.48	average

Table 6. Bearing life (L-10) summary with 25 degree conventional gearing (2H155 gearbox)

UNIT RATIO>	6.3076	6.8421	8.1092	8.7579	9.9522		10.7094	12.7973	13.8109	16.0105	17.2540	
	single helical	single helical	single helical	single helical	single helical		single helical	single helical	single helical	single helical	single helical	
ID #>	155H1	155H2	155H3	155H4	155H5		155H6	155H7	155H8	155H9	155H10	<ID #
Catalog HP	239	216	187	169	154	Catalog HP	138	120	108	96	87	Catalog HP
CENTERS (mm)	109	109	109	109	109	CENTERS (mm)	109	109	109	109	109	CENTERS (mm)
CENTERS (in)	4.291	4.291	4.291	4.291	4.291	CENTERS (in)	4.291	4.291	4.291	4.291	4.291	CENTERS (in)
GEAR TEETH	59	60	64	64	64	GEAR TEETH	72	101	109	117	116	GEAR TEETH
PINION TEETH	32	30	27	25	22	PINION TEETH	23	27	27	25	23	PINION TEETH
RATIO	1.8438	2.0000	2.3704	2.5600	2.9091	RATIO	3.1304	3.7407	4.0370	4.6800	5.0435	RATIO
CENTERS (mm)	155	155	155	155	155	CENTERS (mm)	155	155	155	155	155	CENTERS (mm)
CENTERS (in)	6.102	6.102	6.102	6.102	6.102	CENTERS (in)	6.102	6.102	6.102	6.102	6.102	CENTERS (in)
GEAR TEETH	65	65	65	65	65	GEAR TEETH	65	65	65	65	65	GEAR TEETH
PINION TEETH	19	19	19	19	19	PINION TEETH	19	19	19	19	19	PINION TEETH
RATIO	3.4211	3.4211	3.4211	3.4211	3.4211	RATIO	3.4211	3.4211	3.4211	3.4211	3.4211	RATIO
At Catalog Rating						At Catalog Rating						At Catalog Rating
Shaft 1						Shaft 1						Shaft 1
Left	3779	3720	4881	4111	2744	Left	2744	3070	9340	6448	15511	Left
Right	134463	>200k	>200k	>200k	>200k	Right	>200k	>200k	>200k	>200k	>200k	Right
Shaft 2						Shaft 2						Shaft 2
Left	4191	8223	5300	6877	7892	Left	10358	10321	9674	11205	10699	Left
Right	4333	8014	5630	6501	6468	Right	7792	8343	10499	10820	13262	Right
Shaft 3						Shaft 3						Shaft 3
Left	197885	>200k	>200k	>200k	>200k	Left	>200k	>200k	>200k	>200k	>200k	Left
Right	18504	42183	22267	24752	25214	Right	26905	25209	28683	27498	30517	Right
Bearing HP SF	1.27	1.29	1.27	1.24	1.39	Bearing HP SF	1.39	1.35	1.03	1.15	1	Bearing HP SF
for 10,000 hrs L-10	187.7	167.6	159.2	136.8	110.6	for 10,000 hrs L-10	99.3	88.2	105.3	83.8	87.5	for 10,000 hrs L-10

Table 7. Bearing life (L-10) summary with HCR gearing (2H155 gearbox)

UNIT RATIO>	6.3076	6.8421	8.1092	8.7296	10.0000		10.7519	12.8014	13.8109	16.0526	17.2540	
	single helical	single helical	single helical	single helical	single helical		single helical	single helical	single helical	single helical	single helical	
ID #>	155H1	155H2	155H3	155H4	155H5		155H6	155H7	155H8	155H9	155H10	<ID #
Catalog HP	239	216	187	169	154	Catalog HP	138	120	108	96	87	Catalog HP
CENTERS (mm)	109	109	109	109	109	CENTERS (mm)	109	109	109	109	109	CENTERS (mm)
CENTERS (in)	4.291	4.291	4.291	4.291	4.291	CENTERS (in)	4.291	4.291	4.291	4.291	4.291	CENTERS (in)
GEAR TEETH	59	60	64	74	76	GEAR TEETH	88	116	109	122	116	GEAR TEETH
PINION TEETH	32	30	27	29	26	PINION TEETH	28	31	27	26	23	PINION TEETH
RATIO	1.8438	2.0000	2.3704	2.5517	2.9231	RATIO	3.1429	3.7419	4.0370	4.6923	5.0435	RATIO
CENTERS (mm)	155	155	155	155	155	CENTERS (mm)	155	155	155	155	155	CENTERS (mm)
CENTERS (in)	6.102	6.102	6.102	6.102	6.102	CENTERS (in)	6.102	6.102	6.102	6.102	6.102	CENTERS (in)
GEAR TEETH	65	65	65	65	65	GEAR TEETH	65	65	65	65	65	GEAR TEETH
PINION TEETH	19	19	19	19	19	PINION TEETH	19	19	19	19	19	PINION TEETH
RATIO	3.4211	3.4211	3.4211	3.4211	3.4211	RATIO	3.4211	3.4211	3.4211	3.4211	3.4211	RATIO
At Catalog Rating						At Catalog Rating						At Catalog Rating
Shaft 1						Shaft 1						Shaft 1
Left	3997	3942	5162	8341	6935	Left	7736	11426	16818	15078	16530	Left
Right	>200k	>200k	>200k	>200k	>200k	Right	>200k	>200k	>200k	>200k	>200k	Right
Shaft 2						Shaft 2						Shaft 2
Left	4376	5390	5537	6310	6591	Left	8202	7844	8855	9452	11189	Left
Right	4724	5494	6169	7367	7351	Right	8956	9828	11919	12464	14542	Right
Shaft 3						Shaft 3						Shaft 3
Left	62257	>200k	78539	>200k	>200k	Left	>200k					Left
Right	6355	22681	8010	26434	24200	Right	28132	26659	30363	28859	32259	Right
Bearing HP SF	1.24	1.27	1.14	1.17	1.15	Bearing HP SF	1.09	1.08	1.04	1.02	0.97	Bearing HP SF
for 10,000 hrs L-10	193.1	170.6	163.3	144.8	134	for 10,000 hrs L-10	126.8	110.6	104.1	94.2	90	for 10,000 hrs L-10

Table 8. Bearing life (L-10) summary with 25 degree conventional gearing (2H330 gearbox)

UNIT RATIO>	6.4316	7.0955	8.1579	8.9961	9.8966		10.9211	12.7918	14.0789	15.5373	17.1053	
	single helical	single helical	single helical	single helical	single helical		single helical	single helical	single helical	single helical	single helical	
ID #>	330H1	330H2	330H3	330H4	330H5	<LOCATION	330H6	330H7	330H8	330H9	330H10	<ID #
Catalog HP	1,910	1,810	1,650	1,440	1,370	Catalog HP	1,190	1,070	934	889	770	Catalog HP
CENTERS (mm)	226	226	226	226	226	CENTERS (mm)	226	226	226	226	226	CENTERS (mm)
CENTERS (in)	8.898	8.898	8.898	8.898	8.898	CENTERS (in)	8.898	8.898	8.898	8.898	8.898	CENTERS (in)
GEAR TEETH	47	56	62	71	81	GEAR TEETH	83	86	107	109	95	GEAR TEETH
PINION TEETH	25	27	26	27	28	PINION TEETH	26	23	26	24	19	PINION TEETH
RATIO	1.8800	2.0741	2.3846	2.6296	2.8929	RATIO	3.1923	3.7391	4.1154	4.5417	5.0000	RATIO
CENTERS (mm)	330	330	330	330	330	CENTERS (mm)	330	330	330	330	330	CENTERS (mm)
CENTERS (in)	12.992	12.992	12.992	12.992	12.992	CENTERS (in)	12.992	12.992	12.992	12.992	12.992	CENTERS (in)
GEAR TEETH	65	65	65	65	65	GEAR TEETH	65	65	65	65	65	GEAR TEETH
PINION TEETH	19	19	19	19	19	PINION TEETH	19	19	19	19	19	PINION TEETH
RATIO	3.4211	3.4211	3.4211	3.4211	3.4211	RATIO	3.4211	3.4211	3.4211	3.4211	3.4211	RATIO
At Catalog Rating						At Catalog Rating						At Catalog Rating
Shaft 1						Shaft 1						Shaft 1
Left	3,098	1,546	4,675	1,903	4,265	Left	5,340	5,066	6,277	4,595	5,677	Left
Right	151,608	125,077	166,842	166,489	192,793	Right	>200,000	>200,000	>200,000	>200,000	>200,000	Right
Shaft 2						Shaft 2						Shaft 2
Left	3,678	4,758	4,672	5,633	3,560	Left	4,512	4,435	5,965	5,565	7,743	Left
Right	10,175	5,698	5,599	7,179	7,231	Right	9,258	9,233	11,550	10,872	13,889	Right
Shaft 3						Shaft 3						Shaft 3
Left	>200,000	>200,000	>200,000	>200,000	>200,000	Left	>200,000	>200,000	>200,000	>200,000	>200,000	Left
Right	60,283	52,315	56,289	70,668	66,750	Right	84,823	80,868	97,100	86,785	106,960	Right
Bearing HP SF	1.34	1.65	1.41	1.55	1.21	Bearing HP SF	1.14	1.28	1.19	1.19	1.19	Bearing HP SF
for 10,000 hrs L-10	1423.8	1099.6	1169.4	932	1129	for 10,000 hrs L-10	1046	838.1	786.3	748.3	649.6	for 10,000 hrs L-10

Table 9. Conventional gearing (2H155 gearbox

UNIT RATIO>	6.4091	7.0381	8.1575	8.9646	9.8620		10.8829	12.7470	14.0297	15.4830	17.2004	
	single helical	single helical	single helical	single helical	single helical		single helical	single helical	single helical	single helical	single helical	
ID #>	330H1	330H2	330H3	330H4	330H5		330H6	330H7	330H8	330H9	330H10	<ID #
Catalog HP	1,910	1,810	1,650	1,440	1,370	Catalog HP	1,190	1,070	934	889	770	Catalog HP
CENTERS (mm)	226	226	226	226	226	CENTERS (mm)	226	226	226	226	226	CENTERS (mm)
CENTERS (in)	8.898	8.898	8.898	8.898	8.898	CENTERS (in)	8.898	8.898	8.898	8.898	8.898	CENTERS (in)
GEAR TEETH	47	64	67	71	81	GEAR TEETH	83	86	107	109	111	GEAR TEETH
PINION TEETH	25	31	28	27	28	PINION TEETH	26	23	26	24	22	PINION TEETH
RATIO	1.8800	2.0645	2.3929	2.6296	2.8929	RATIO	3.1923	3.7391	4.1154	4.5417	5.0455	RATIO
CENTERS (mm)	330	330	330	330	330	CENTERS (mm)	330	330	330	330	330	CENTERS (mm)
CENTERS (in)	12.992	12.992	12.992	12.992	12.992	CENTERS (in)	12.992	12.992	12.992	12.992	12.992	CENTERS (in)
GEAR TEETH	75	75	75	75	75	GEAR TEETH	75	75	75	75	75	GEAR TEETH
PINION TEETH	22	22	22	22	22	PINION TEETH	22	22	22	22	22	PINION TEETH
RATIO	3.4091	3.4091	3.4091	3.4091	3.4091	RATIO	3.4091	3.4091	3.4091	3.4091	3.4091	RATIO
At Catalog Rating						At Catalog Rating						At Catalog Rating
Shaft 1						Shaft 1						Shaft 1
Left	3,295	3,492	2,544	6,705	4,549	Left	7,018	5,399	6,669	6,030	7,284	Left
Right	179,014	>200,000	170,958	>200,000	>200,000	Right	>200,000	>200,000	>200,000	>200,000	>200,000	Right
Shaft 2						Shaft 2						Shaft 2
Left	3,828	3,982	3,862	3,609	3,800	Left	4,820	4,740	6,387	5,962	7,663	Left
Right	6,797	6,631	6,477	8,577	8,011	Right	10,271	10,262	12,862	12,119	15,720	Right
Shaft 3						Shaft 3						Shaft 3
Left	>200,000	>200,000	>200,000	>200,000	>200,000	Left	>200,000	>200,000	>200,000	>200,000	>200,000	Left
Right	65,413	62,817	61,278	77,276	72,283	Right	92,339	88,069	105,728	94,466	116,134	Right
Bearing HP SF	1.31	1.29	1.42	1.34	1.34	Bearing HP SF	1.24	1.25	1.15	1.17	1.10	Bearing HP SF
for 10,000 hrs L-10	1456	1402.8	1165.3	1077.2	1022.5	for 10,000 hrs L-10	956.3	854.2	815.3	759	700	for 10,000 hrs L-10

Conclusion

The industry has devoted much of the last one hundred forty years to exploiting the “standard” full depth tooth form. We moved from simple cast teeth to highly modified carburized and ground ones as market demands grew and technology became available. An opportunity exists to increase the capacity of our products by 25 percent or more while simultaneously meeting stringent noise standards through the adoption of a deeper than “full depth” tooth geometry that has already been successful in aerospace and vehicle equipment.

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