1601 36th Avenue West, Alexandria, MN 56308
PH 320-762-1645 FX 320-762-2819 www.itwheartland.com/spiroid/

SPIROID® AND HELICON® GEARING

Written by:
DuWayne Paul
Director of Sales
Spiroid® - A Business Unit of ITW Heartland
Email: duwayne.paul@itwheartland.com
Web: www.itwheartland.com/Spiroid/

Synonyms
Spiroid® – skew axis gearing with tapered pinion
Helicon® – skew axis gearing without tapered pinion
IP – intellectual property

Definition
The Spiroid family of gears consists of two trademarked brands, Spiroid® and Helicon®. This type of gearing, often referred to as "skew axis gearing", operates on nonintersecting and nonparallel axes. It is designed and produced using software, tooling, and methods developed by Illinois Tool Works, who owns and maintains the IP. It is exclusively designed for right angle power transmission where high amounts of torque are required from a small gearbox envelope. A variety of materials can be used including steel, brass, aluminum bronze, forgings, powder metal, and plastic (either molded or cut). Typical features include high torque capability, high stiffness, quiet running, compact and lightweight, and easy to assemble. Ratios are available ranging from 3:1 to more than 400:1.

Fig. 1a shows the relationship of Spiroid® and Helicon® to traditional right angle power transmission methods (bevel gearing and worm gearing). Fig. 1b shows examples of Spiroid® and Helicon® gearsets.

As you can note, the offset from the gear centerline allows the Spiroid® and Helicon® gearing to maintain more tooth surface to be in contact at any one time, thus increasing the contact ratio. By increasing the contact ratio, higher amounts of torque capacity are generated and motion transmission is smoother.

Continued:

1601 36th Avenue West, Alexandria, MN 56308
PH 320-762-1645 FX 320-762-2819 www.itwheartland.com/spiroid/

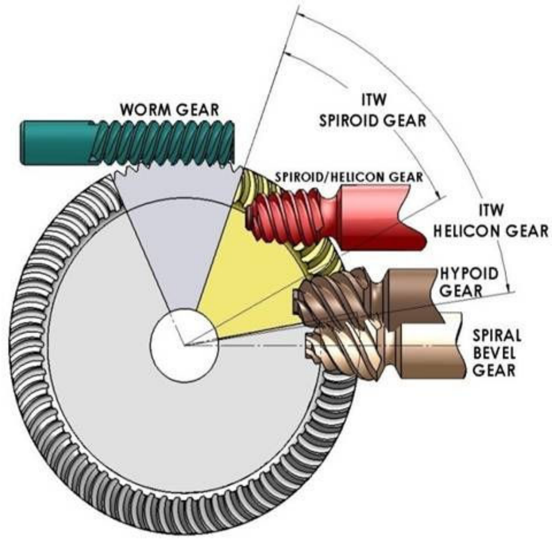


Figure 1a

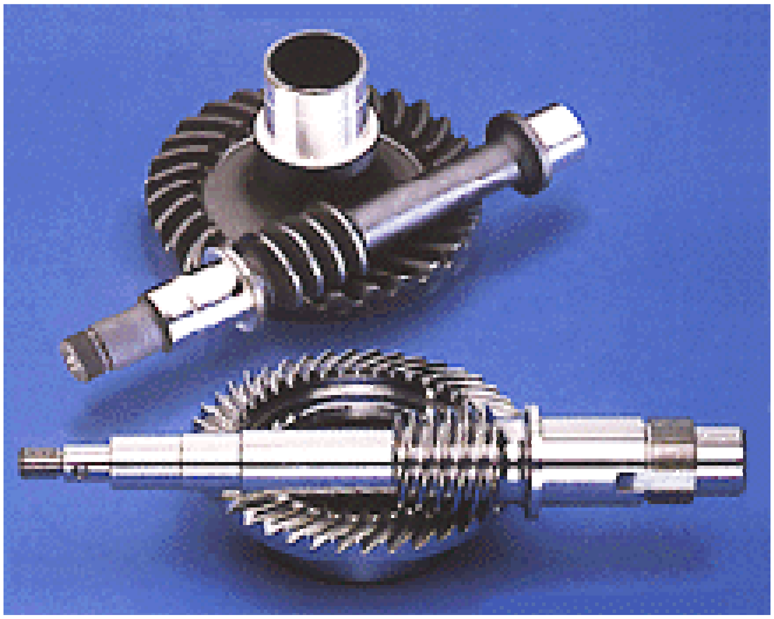


Figure 1b

Figure 1 Spiroid® and Helicon® gearing. 1a) Spiroid® and Helicon® compared to bevel and worm gearsets. 1b) Photograph of Spiroid® and Helicon® gearsets.

1601 36th Avenue West, Alexandria, MN 56308
PH 320-762-1645 FX 320-762-2819 www.itwheartland.com/spiroid/

Scientific Fundamentals

Key Characteristics

- Simple and positive backlash control – in some applications, backlash can be maintained at zero
- Available as either right hand or left hand
- Can be driven either direction
- Ability to adjust mounting distance based on assembly variation
- Very high accuracy for precise positioning or indexing and constant velocity
- Very high reduction ratios possible
- Superior shock strength
- Very high torque capability in relationship to size of gearset
- Quiet operation
- Versatility of material that can be used
- Compact and lightweight
- High stiffness
- Design flexibility – gearsets are designed to meet the application requirements, rather than developing the application requirements to meet the gearing method

Contact Characteristics

It should be pointed out that all gears can, at best, obtain only line contact under no load conditions, at any instantaneous position of mesh. The total length of line contact is one criterion of gear load carrying capabilities. Another is contact line movement during the engagement cycle. The contact line should not be stationary. It should sweep the entire available tooth surface. Movement or sweep of the contact line brings freshly lubricated and cool areas into mesh. This applies to all gears. Other factors, such as relative curvature of contacting surfaces and inclination of the contact lines relative to sliding velocity, must also be considered. With Spiroid® and Helicon® pinions, the line of instantaneous contact is an almost radial line on each convolution of the pinion thread. It is almost perpendicular to the sliding velocity, and results in a full sweep of contact on the pinion and gear.

By contrast, the instantaneous line of contact for worm gears is only slightly inclined to the direction of sliding velocity. This results in a narrow band of contact on the worm thread.

Continued:

1601 36th Avenue West, Alexandria, MN 56308
PH 320-762-1645 FX 320-762-2819 www.itwheartland.com/spiroid/

Gear Rotation
Depending on the hand of the pinion thread, a Spiroid® or Helicon® gearset is called either right hand or left hand. Either hand can be positioned with the gear in any of four different gear quadrants, allowing for flexibility in the gearbox design. The relative directions of rotation and preferred directions of rotation allow for maximum bearing life.

Indexing and Rotational Accuracy
Indexing accuracy of gears is often given in minutes or seconds of arc. Other applications demand that the rotational speed of the gear not vary more than a fixed percentage of the average speed.

Like all gears, Spiroid® and Helicon® gears inherit their initial accuracy from the machines that produce them. However, Spiroid® and Helicon® gears have features that minimize the effect of manufacturing deviations. For example, the large number of pinion teeth in simultaneous contact with the gear teeth helps average out some of the deviations existing on the individual teeth.

Gear tooth and pinion thread runouts cause angular velocity fluctuation, the magnitude of which is effected by the pressure angle. The greater the pressure angle, the greater the fluctuation in angular velocity. Therefore, the low pressure angle side should be used as the driving side in applications requiring low angular velocity fluctuations.

Pressure angles as low as 5 degrees are attainable in many reduction ratios for both Spiroid® and Helicon® gears.

Multiple Tooth Contact
Spiroid® and Helicon® gears have many teeth in simultaneous contact. This, coupled with the fact that each pinion tooth contacts its mating gear tooth along a line perpendicular to the sliding velocity, leads to a number of important advantages.

The number of teeth in contact depends on the number of teeth in the gear member. Generally, 10% of the gear teeth are in simultaneous contact. However, even in the low ratio range, there is two to three times the number of teeth in contact, as compared to worm gears. On higher ratios, there are many times more.

`

Continued:

Heartland Spiroid

1601 36th Avenue West, Alexandria, MN 56308
PH 320-762-1645 FX 320-762-2819 www.itwheartland.com/spiroid/

For any gear of a given diameter, a higher ratio means more teeth, which means a finer pitch. Since contact between the Spiroid® and Helicon® pinion and gear extends over the entire length of the pinion, a finer pitch or shorter lead gives a proportionately increased number of teeth in simultaneous contact, and thus, very little sacrifice in capacity (higher torque capability from smaller gears). With worm gears, for instance, the upper ratio limit is usually about 80;1. After selecting a pitch sufficient to carry the required load (bearing in mind that, at most, the worm set has two teeth in contact) the gear becomes too large. Consequently, in the case of worm gearing, higher ratios are usually handled by multiple reductions.

Spiroid® and Helicon® gears, however, do not have an upper limitation. For a given gear diameter, a higher ratio means a shorter lead and finer pitch, and with more teeth in contact. As a result, single reduction ratios of up to 400:1 are possible.

High Side and Low Side

Spiroid® and Helicon® tooth pressure angles are not symmetrical. However, they operate at about the same efficiency and load rating in either direction of pinion rotation, even though direction and magnitude of the forces on the teeth are different. While the resultant tooth forces are largely in the axial direction of the pinion (particularly in the higher ratio range) they also have components working in the radial direction of the pinion. This tends to separate the pinion and gear teeth. The radial component is greater when the high pressure angle of the tooth does the driving.

Materials

The more favorable contact conditions and lower sliding between Spiroid® and Helicon® gear members permits the use of steel grades that can be hardened, for both gears and pinions. This, plus the ideal lubricating film formation, and the movement of the contact lines, makes the use of hardened steel-on-steel an ideal material for both Spiroid® and Helicon® gearsets. In worm gears, by contrast, the usual selection is a hardened steel worm meshing with a bronze gear.

Quietness

Gear accuracy is the most important factor in obtaining maximum quietness and minimum vibration. However, at high pitch line velocities, even small inaccuracies can produce a pronounced noise, particularly if they occur at regular frequencies. Therefore, to achieve quiet gears, accuracy is combined with modifications in the profile and lead of the gear teeth, permitting them to engage gradually. It was previously pointed out that the contact lines on Spiroid® and

Continued:

1601 36th Avenue West, Alexandria, MN 56308
PH 320-762-1645 FX 320-762-2819 www.itwheartland.com/spiroid/

Helicon® pinions are nearly radial, and sweep the entire length of the teeth. At such great tooth length, very effective modifications can be made at the entering and leaving side, so the pinion teeth "cam" into and out of the action gently. The commonly used term for these modifications is "crowning". Incorporated in either the pinion of the gear, and in conjunction with the large number of teeth in simultaneous engagement, it accounts for the fact the Spiroid® and Helicon® gears are inherently very quiet.

Efficiency
The efficiency of a gearset is a measure of the power lost in the gear mesh, which turns into heat that must be dissipated. Thus a gearset, which is 70% efficient, loses 30% of the power input and transmits 70%. The efficiency of Spiroid® and Helicon® gearsets, as well as all other gear types, is a function of the gearset geometry, i.e. the efficiency angles, and coefficient of friction. Spiroid® and Helicon® gearset geometry and ideal lubricating characteristics provide for inherently high efficiencies when compared to worm gears.

As with all other gear types, the higher the gearset ratio, the lower the efficiency. Sometimes, however, the low efficiency can be an asset, particularly when "self-locking" is desired. Self-locking is the inability of the gear to drive the pinion, or back drive, and is a characteristic common to higher ratios gearsets. Special design considerations can accommodate application requirements for higher dynamic efficiencies or self-locking efficiencies through the custom design versatility of Spiroid® and Helicon® gearing.

Mounting
Spiroid® and Helicon® pinion mountings are more rigid than worm gearing because the bearings can be located very close to the working gear mesh. The cantilever style mounting of the pinion conforms to accepted bevel gear practice. The cantilever design may be changed to a through shaft design for additional rigidity. Another useful mounting is the short straddle mount where the through shaft is supported by a needle bearing. This mounting becomes particularly useful where extremely high stiffness is required.

Continued:

1601 36th Avenue West, Alexandria, MN 56308
PH 320-762-1645 FX 320-762-2819 www.itwheartland.com/spiroid/

Axial Positioning and Backlash Control

Many modern gear applications demand controllable "near zero" backlash control. For example, applications requiring precise positioning or indexing, or systems with frequent load reversals, benefit from simple backlash adjustment.

Both Spiroid® and Helicon® pinions have threads of constant lead and pressure angle. A Helicon® is completely insensitive to its axial position. Spiroid® pinions are insensitive within the limits of movement necessary for backlash control.

The same is true for Spiroid® and Helicon® gears as far as their axial position is concerned. This feature provides for easy backlash adjustment by merely moving the gear along its axis.

Since the Spiroid® pinion also is adjustable along its axis within a range of positions, there are new opportunities for finer backlash control. No other type of gearing offers this feature in such a simple and direct way.

Key Applications

Spiroid® and Helicon® gearing is especially advantageous for applications that require a right angle gearset, high torque in a small space, and lightweight. Traditionally, these have been in military and aerospace application, but it can be used in any application with similar requirements.

Examples of Spiroid® and Helicon® Gearing

Below are examples of the two gearing types addressed in this article. They are compared to each other with the same parameters. These examples can then be taken and compared to worm gearing or bevel gearing using the same design parameters.

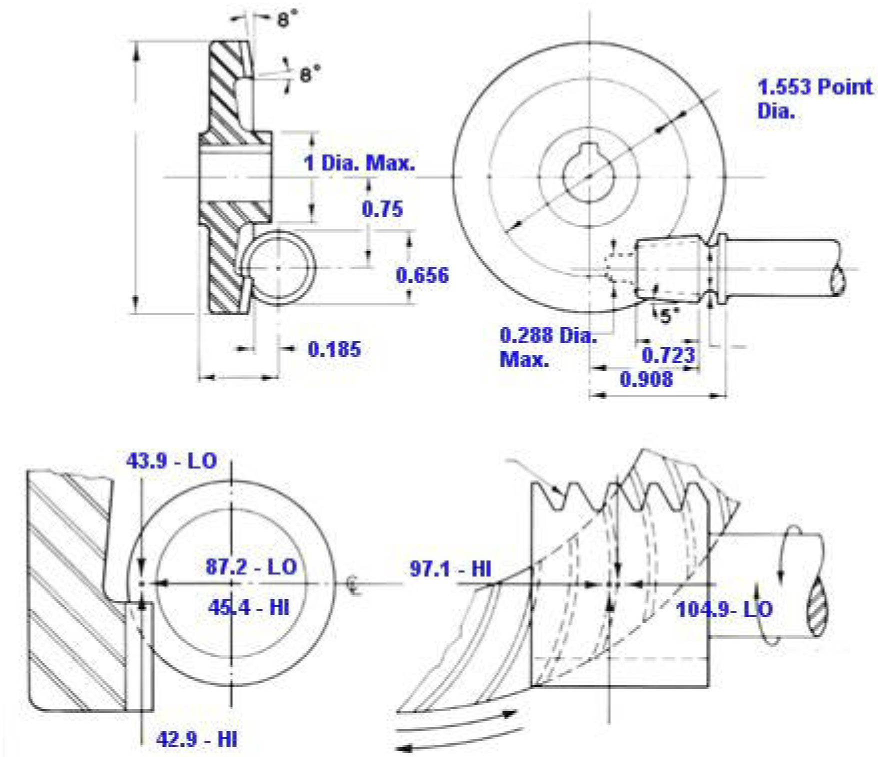
Continued:

Heartland Spiroid

1601 36th Avenue West, Alexandria, MN 56308
PH 320-762-1645 FX 320-762-2819 www.itwheartland.com/spiroid/

Example 1 – **Spiroid® Tooth Style**
Parameters:

- 2.250 inch gear OD
- Material – Steel on Steel
- Moderate shock load
- Electric motor input – 24 hrs per day
- Pinion speed 1200
- Ratio – 10:1
- Peak torque output – 170 inch pounds



Dimension Data

- Pressure Angle Low – 15
- Pressure Angle High – 35

Efficiency = .866
Material Factor = 1.00
Output Capacity = 170
Service Factor = 1.50

Tooth Load Data

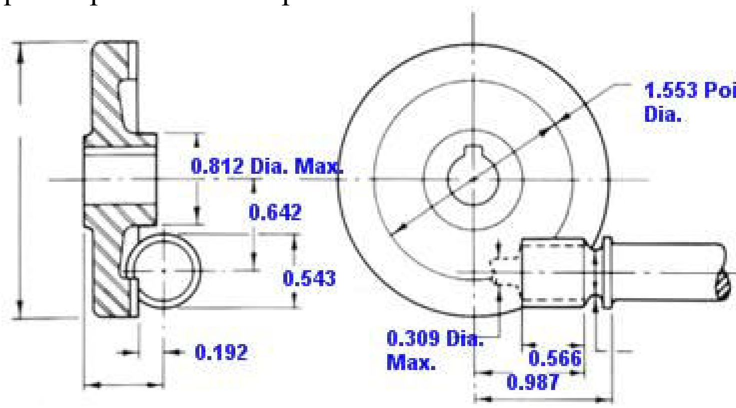
	Low Side	High Side
Fx	1.049	0.971
Fy	0.454	0.872
Fz	0.429	0.439

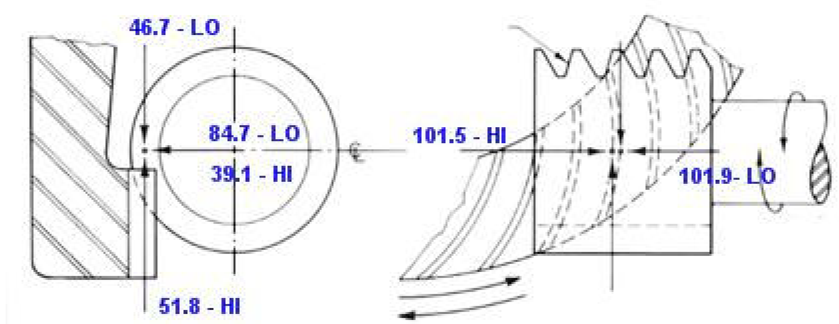
Continued:

Heartland Spiroid
1601 36th Avenue West, Alexandria, MN 56308
PH 320-762-1645 FX 320-762-2819 www.itwheartland.com/spiroid/

Example 2 – **Helicon® Tooth Style**
Parameters:

- 2.250 inch gear OD
- Material – Steel on Steel
- Moderate shock load
- Electric motor input – 24 hrs per day
- Pinion speed 1200
- Ratio – 10:1
- Peak torque output – 170 inch pounds





Dimension Data

- Pressure Angle Low – 15
- Pressure Angle High – 32.5

Efficiency = .847
Material Factor = 1.00
Output Capacity = 170
Service Factor = 1.50

Tooth Load Data

	Low Side	High Side
Fx	1.019	1.015
Fy	0.391	0.847
Fz	0.518	0.467

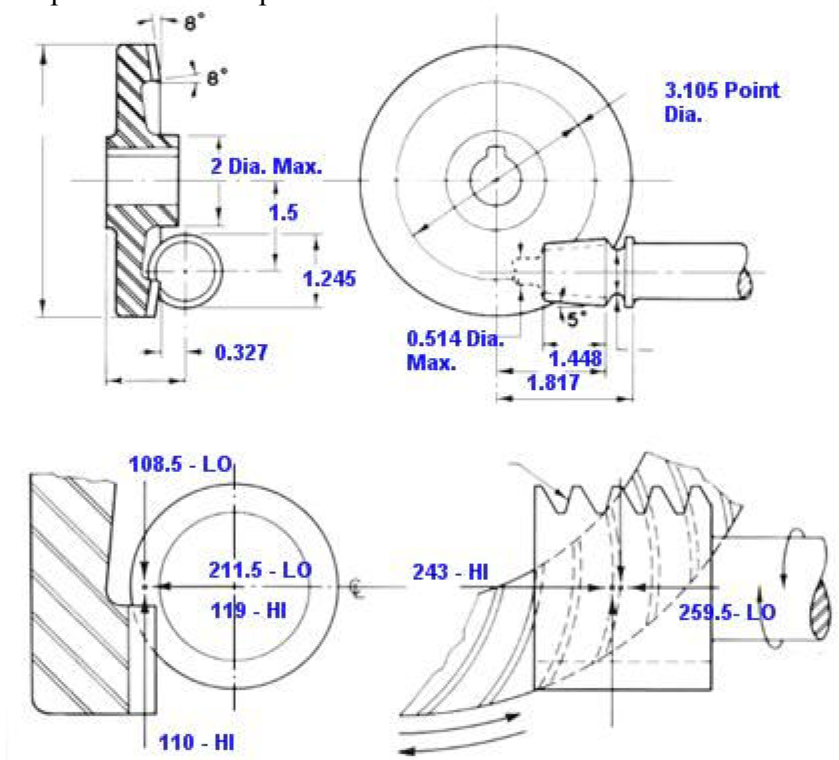
Continued:

Heartland Spiroid

1601 36th Avenue West, Alexandria, MN 56308
PH 320-762-1645 FX 320-762-2819 www.itwheartland.com/spiroid/

Example 3 – **Spiroid® Tooth Style**
Parameters:

- 4.500 inch gear OD
- Material – Steel on Steel
- Moderate shock load
- Electric motor input – 24 hrs per day
- Pinion speed 1200
- Ratio – 10:1
- Torque output – 1133 inch pounds



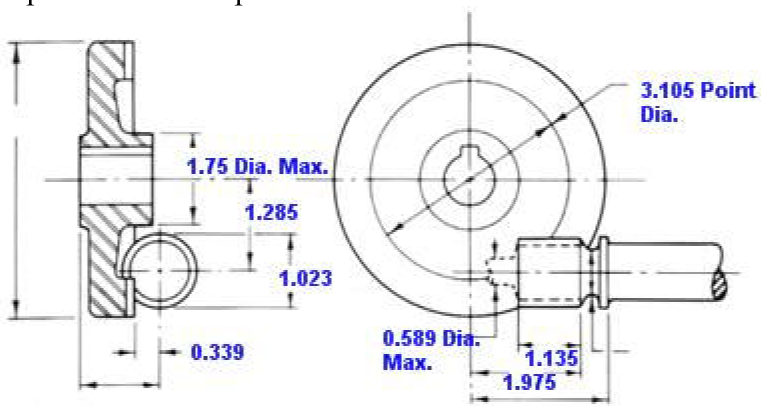
Dimension Data	Tooth Load Data	Low Side	High Side
- Pressure Angle Low – 15	Fx	0.519	0.486
- Pressure Angle High – 32.5	Fy	0.238	0.423
	Fz	0.220	0.217

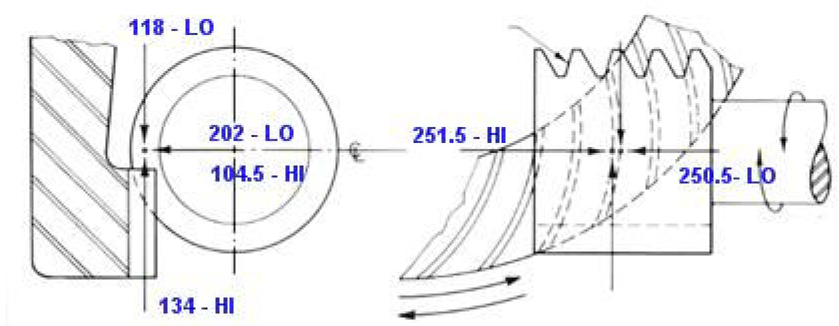
Efficiency = .878
Material Factor = 1.00
Output Capacity = 1133
Service Factor = 1.50

Continued:

Example 4 – **Helicon® Tooth Style**
Parameters:

- 4.500 inch gear OD
- Material – Steel on Steel
- Moderate shock load
- Electric motor input – 24 hrs per day
- Pinion speed 1200
- Ratio – 10:1
- Torque output – 1140 inch pounds





Dimension Data

- Pressure Angle Low – 15
- Pressure Angle High – 30.0

Tooth Load Data

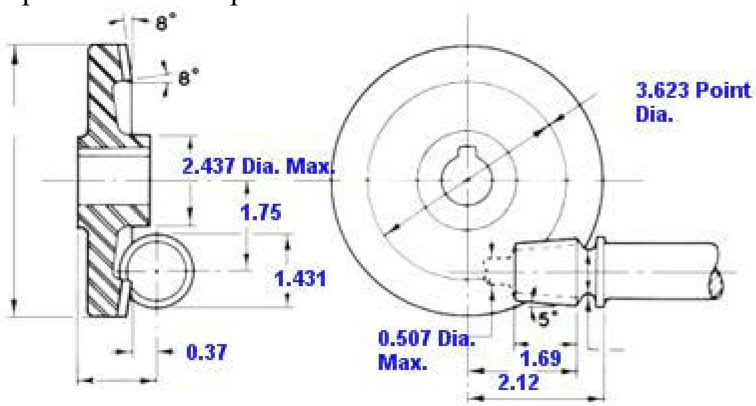
	Low Side	High Side
Fx	0.501	0.503
Fy	0.209	0.404
Fz	0.268	0.236

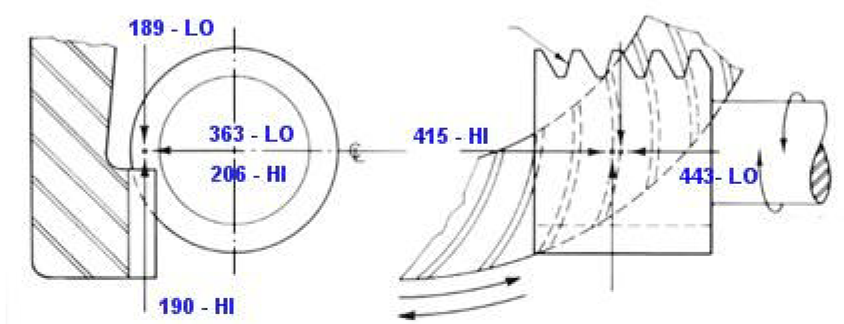
Efficiency = .894
Material Factor = 1.00
Output Capacity = 1140
Service Factor = 1.50

Continued:

Example 5 – **Spiroid® Tooth Style**
Parameters:

- 5.250 inch gear OD
- Material – Steel on Steel
- Moderate shock load
- Electric motor input – 24 hrs per day
- Pinion speed 1200
- Ratio – 10:1
- Torque output – 1698 inch pounds





Dimension Data

- Pressure Angle Low – 15
- Pressure Angle High – 32.5

Efficiency = .884
Material Factor = 1.00
Output Capacity = 1698
Service Factor = 1.50

Tooth Load Data

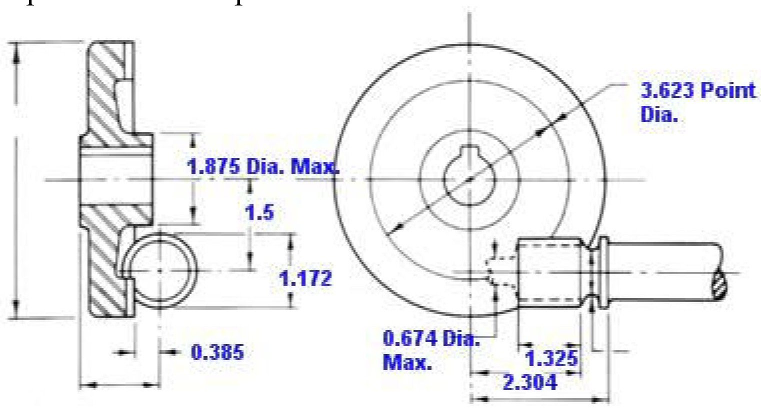
	Low Side	High Side
Fx	0.443	0.415
Fy	0.206	0.363
Fz	0.190	0.189

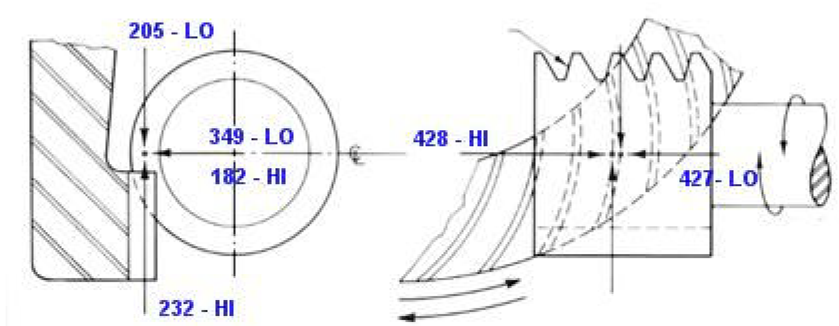
Continued:

1601 36th Avenue West, Alexandria, MN 56308
PH 320-762-1645 FX 320-762-2819 www.itwheartland.com/spiroid/

Example 6 – **Helicon® Tooth Style**
Parameters:

- 5.250 inch gear OD
- Material – Steel on Steel
- Moderate shock load
- Electric motor input – 24 hrs per day
- Pinion speed 1200
- Ratio – 10:1
- Torque output – 1709 inch pounds





Dimension Data		Tooth Load Data	
		Low Side	High Side
- Pressure Angle Low – 15	Fx	0.427	0.428
- Pressure Angle High – 30.0	Fy	0.182	0.349
	Fz	0.232	0.205

Efficiency = .90
Material Factor = 1.00
Output Capacity = 1709
Service Factor = 1.50

Continued:

References

Darle W. Dudley, "Handbook of Practical Gear Design", CRC Press, 1994

ITW Spiroid, "Spiroid Gearing Design Manual No. 6", Illinois Tool Works, 1986

Litvin, F.L., "Development of Gear Technology and Theory of Gearing," NASA Reference Publication 1406, ARL-TR-1500, Biography 3.15, Oliver E. Saari-Inventor at the Illinois Tool Works (ITW) Spiroid Division, 1997

Saari, O.E., "Speed-Reduction Gearing," U.S. Patent No. 2,696,125, 1954

Saari, O.E., "Skew Axis Gearing," U.S. Patent No. 2,954,704, 1960

Bohle, F., and Saari, O., "Spiroid Gears- A New Development in Gearing," AGMA Paper No. 389.01, 1955