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Reverse engineering a gear

Is it an art or is it a science? Facts are irrefutable – but sometimes the gear detective must use experience and imagination to fill in the gaps to identify the correct combination for a new gear.

All of the great literary detectives have that "eureka" moment when the facts they have observed allow them to reach a solid conclusion regarding the case at hand. The facts can be physical clues such as fingerprints or fiber samples, or they can be visual clues such as an out-of-place object, or they can be auditory clues. Since gears don't vocalize very well, it is up to the gear expert to use measurements and formulas to reverse engineer those gears that have failed and require replacement.

Similar to a fingerprint, some gear manufacturers stamp a part number or serial number on the part. This is typically done to gears that are supplied as a stock product by a gear manufacturer, and it is also typical for gears that are assembled in consumer goods. When the identifier is the catalog number from a stock gear manufacturer, then the process of reverse engineering the gear is 90 percent complete. One needs to review the stock gear manufacturer's catalog page and identify any differences. If the gear matches the stock product, your next step is to confirm the current availability of the stock gear with the manufacturer. If the dimensions vary from the stock product offering, then the engineer must decide if the modifications that are needed are some that need to be done by the gear manufacturer or if the modifications can be performed in-house. Some of the common modifications include opening of the bore, the addition of keyslots, the addition of tapped holes in the hub, the addition of lightening holes to remove weight, and the heat treating of teeth in order to increase the gear tooth hardness.

If the gear is marked with a serial number or an OEM internal part number, then the easiest way to replace the gear is to contact the OEM of the product. Unfortunately, it is rare that an OEM has replacement gears to offer and that leads to the end-user needing to go through the process of determining if the cost of producing a single gear is cost effective.

When beginning the reverse engineering process, the first task is to count the number of teeth on the gear. The number of teeth is one of the fundamental values when specifying a gear. If the gear in question is a spur gear and the number of teeth is determined, the next step is to measure the outermost diameter of the teeth. Using this measurement and the number of teeth, the engineer can plug the values into the formula for outside diameter and see if the value for pitch is a rational value.

An example of this would be as follows:

A gear is found to have 24 teeth. The engineer measures the outermost diameter and the value is 39 millimeters. Using the formula: OD = pitch * (number of teeth + 2), it would be determined that the pitch is most likely Module 1.5.

Figure 1: Example of gear pitch gauges.

When reverse engineering a helical gear, the addition of the helix angle adds another step to the identification process.

However, if the same gear measured 1.625 inches, then it would be assumed that the gear pitch is 16DP.

This calculation applies only if the gear is not profile shifted. If it has been profile shifted, then the standard calculation for outside diameter no longer applies. The calculation is also subjective as there is the strong likelihood that the gear has worn on the outermost diameter and will measure smaller than the original manufactured dimension. In order to confirm that pitch of the worn gear, it is necessary to find out the number of teeth of the mating gear and the center distance of the two gears. By measuring the distance between the centers of the two shafts supporting the gears and comparing it to the sum of the pitch radius for each gear, you can confirm the assumption of pitch from the prior calculation.

A secondary method of determining the pitch is to use a pitch gauge (Figure 1). Gear gauges are produced in the most common tooth pitch sizes for both inch and metric pitches and they are also produced in several pressure angle configurations. To use the gauge, you need to place the gauge into the tooth and rotate it through the gauge. Doing this with various sizes will allow you to find the proper fit and thereby identify the proper pitch of the gear.

When reverse engineering a helical gear, the addition of the helix

No.	Item	Symbol	Formula	Example	
				Pinion (1)	Gear (2)
1	Normal module	m_n	Set Value	3	
2	Normal pressure angle	α_n		20°	
3	Reference cylinder helix angle	β		30°	
4	Number of teeth & helical hand	z		12 (L)	60 (R)
5	Normal coefficient of profile shift	x_n		+ 0.09809	0
6	Transverse pressure angle	α_t	$\tan^{-1}\left(\frac{\tan\alpha_n}{\cos\beta}\right)$	22.79588°	
7	Involute function α_{wt}	$\text{inv}\,\alpha_{wt}$	$2\tan\alpha_n\left(\frac{x_{n1}+x_{n2}}{z_1+z_2}\right)+\text{inv}\,\alpha_t$	0.023405	
8	Transverse working pressure angle	α_{wt}	Find from involute Function Table	23.1126°	
9	Center distance modification coefficient	y	$\frac{z_1+z_2}{2\cos\beta}\left(\frac{\cos\alpha_t}{\cos\alpha_{wt}}-1\right)$	0.09744	
10	Center distance	a	$\left(\frac{z_1+z_2}{2\cos\beta}+y\right)m_n$	125.000	
11	Reference diameter	d	$\frac{zm_n}{\cos\beta}$	41.569	207.846
12	Base diameter	d_b	$d\cos\alpha_t$	38.322	191.611
13	Working pitch diameter	d_w	$\frac{d_b}{\cos\alpha_{wt}}$	41.667	208.333
14	Addendum	h_{a1} h_{a2}	$(1+y-x_{n2})m_n$ $(1+y-x_{n1})m_n$	3.292	2.998
15	Tooth depth	h	$\{2.25+y-(x_{n1}+x_{n2})\}\,m_n$	6.748	
16	Tip diameter	d_a	$d+2h_a$	48.153	213.842
17	Root diameter	d_f	d_a-2h	34.657	200.346

Table 1: The calculations of a profile shifted helical gear.

angle adds another step to the identification process. Since the outermost diameter of a helical gear is determined by the pitch, the number of teeth, and helix angle, it becomes imperative to identify either the pitch or the helix angle. Using a gear gauge to identify the pitch, the helix angle can be determined by the formula: OD = (pitch * (number of teeth +2)) / cos (helix angle).

As with the spur gear calculation, this formula applies only if the gear is not profile shifted. If it has been profile shifted, then the standard calculation for outside diameter no longer applies. An example of the calculations of a profile shifted helical gear is detailed in Table 1.

As detailed in Table 1, too many variables are needed to reverse engineer a profile shifted helical gear. In this case, it is the engineer's experience that will help to determine the best values for the required gear. In order to best replace the worn gear, the engineer should choose to specify a new set of gears that fit the center distance of the existing pair instead of trying to replace just the worn gear.

Reverse engineering spur and helical gearing is both an art and a science. Using the clues provided by the sample gear and the known gear geometry formulas, it is possible to identify pitch of the gear that needs replacement. With this data, the engineer can determine what material and hardness would be best for the new gear.

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