the straight track on GEAR RACKS

By Bill Haag, Sr.
Readers of this magazine are more than familiar with gears and typical applications, of course, but most of them have only a passing acquaintance with gear racks. A gear rack is essentially a gear that is cut on a horizontal plane. The rack thus facilitates linear travel, as opposed to most gear applications, delivering power and/or controlling speed. A rack is normally used with a matching pinion.

In some cases the pinion, as the source of power, drives the rack for locomotion. This would be typical in a drill press spindle or a slide out mechanism where the pinion is stationary and drives the rack with the loaded mechanism that needs to be moved. In other cases the rack is fixed stationary and the pinion travels the length of the rack, delivering the load. A typical example would be a lathe carriage with the rack fixed to the underside of the lathe bed, where the pinion drives the lathe saddle. Another example would be a construction elevator that may be 30 stories tall, with the pinion driving the platform from the ground to the top level.

Anyone considering a rack and pinion application would be well advised to purchase both of them from the same source—some companies that produce racks do not produce gears, and many companies that produce gears do not produce gear racks.

The customer should seek singular responsibility for smooth, problem-free power transmission. In the event of a problem, the customer should not be in a position where the gear source claims his product is correct and the rack supplier is claiming the same. The customer has no wish to become a gear and gear rack expert, let alone be a referee to claims of innocence. The customer should be in the position to make one phone call, say “I have a problem,” and expect to get an answer.

Unlike other forms of linear power travel, a gear rack can be butted end to end to provide a virtually limitless length of travel. This is best accomplished by having the rack supplier “mill and match” the rack so that each end of each rack has one-half of a circular pitch. This is done to a plus .000", minus an appropriate dimension, so that the “butted together” racks cannot be more than one circular pitch from rack to rack. A small gap is acceptable. The correct spacing is arrived at by simply putting a short piece of rack over the joint so that several teeth of each rack are engaged and clamping the location tightly until the positioned racks can be fastened into place (see figure 1).
A few words about design: While most gear and rack manufacturers are not in the design business, it is always helpful to have the rack and pinion manufacturer involved on the early phase of concept development.

Only the original equipment manufacturer (the customer) can determine the loads and service life, and control the installation of the rack and pinion. However, our customers often benefit from our 75 years of experience in producing racks and pinions. We can often save considerable amounts of time and money for our customers by seeing the rack and pinion specifications early on.

The most common lengths of stock racks are six feet and 12 feet. Specials can be made to any practical length, within the limits of material availability and machine capacity. Racks can be produced in diametral pitch, circular pitch, or metric dimensions, and they can be produced in either 14 1/2 degree or 20 degree pressure angle. Special pressure angles can be made with special tooling.

In general, the wider the pressure angle, the smoother the pinion will roll. It’s not uncommon to go to a 25-degree pressure angle.

FIGURE 2

14.5 PA

20 PA

25 PA
angle in a case of extremely heavy loads and for situations where more strength is required (see figure 2).

Racks and pinions can be beefed up, strength-wise, by simply going to a wider face width than standard. Pinions should be made with as large a number of teeth as is possible, and practical. The larger the number of teeth, the larger the radius of the pitch line, and the more teeth are engaged with the rack, either fully or partially. This results in a smoother engagement and performance (see figure 3).

Note: in figure 3, the 30-tooth pinion has three teeth in almost full engagement, and two more in partial engagement. The 13-tooth pinion has one tooth in full contact and two in partial contact. As a rule, you should never go below 13 or 14 teeth. The small number of teeth results in an undercut in the root of the tooth, which makes for a “bumpy ride.” Sometimes, when space is a problem, a simple solution is to put 12 teeth on a 13-tooth diameter. This is only suitable for low-speed applications, however.
Another way to achieve a “smoother” ride, with more tooth engagement and higher load carrying capacity, is to use helical racks and pinions. The helix angle gives more contact, as the teeth of the pinion come into full engagement and then leave engagement with the rack.

As a general rule the strength calculation for the pinion is the limiting factor. Racks are generally calculated to be 300 to 400 percent stronger for the same pitch and pressure angle if you stick to normal rules of rack face and material thickness. However, each situation should be calculated on its own merits. There should be at least two times the tooth depth of material below the root of the tooth on any rack—the more the better, and stronger.

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Gears and gear racks, like all gears, should have backlash designed into their mounting dimension. If they don’t have enough backlash, there will be a lack of smoothness in action, and there will be premature wear. For this reason, gears and gear racks should never be used as a measuring device, unless the application is fairly crude. Scales of most types are far superior in measuring than counting revolutions or teeth on a rack.

Occasionally a customer will feel that they need to have a zero-backlash setup. To do this, some pressure—such as spring loading—is exerted on the pinion. Or, after a test run, the pinion is set to the closest fit that allows smooth running rather than setting to the recommended backlash for the given pitch and pressure angle. If a customer is seeking a tighter backlash than normal AGMA recommendations, they may order racks to special pitch and straightness tolerances.

Straightness in gear racks is an atypical subject in a business like gears, where tight precision is the norm. Most racks are produced from cold-drawn materials, which have stresses built into them from the cold-drawing process. A piece of rack will probably never be as straight as it was before the teeth are cut.

The most modern, state of the art rack machine presses down and holds the material with thousands of pounds of force in order to get the most perfect pitch line that’s possible when cutting the teeth. Old-style, conventional machines usually just beat it as flat as the operator could with a clamp and hammer.

When the teeth are cut, stresses are relieved on the side with the teeth, causing the rack to bow up in the middle after it is released from the machine chuck. The rack must be straightened to make it usable. This is done in a variety of ways, depending upon the size of the material, the grade of material, and the size of teeth.

Occasionally, gear racks will get memory—returning to an “unstraight” condition—after they have been straightened. This usually happens when racks are exposed to large swings in ambient temperature (150 degrees in a truck crossing the desert, for instance) and bouncing around in that truck bed for several hundred miles. The memory is usually not as severe as when the racks come out of the cutting machine, but it can be disconcerting to the customer. Bowing can be
minimized—but never totally eliminated—by stress-relieving material. But this is not practical, or possible, in many small-quantity applications.

I often use the analogy that “A gear rack has the straightness integrity of a noodle,” and this is only a slight exaggeration. A gear rack gets the best straightness, and therefore the smoothest operations, by being mounted flat on a machined surface and bolted through the bottom rather than through the side. The bolts will pull the rack as flat as possible, and as flat as the machined surface will allow. This replicates the flatness and flat pitch line of the rack cutting machine.

Other mounting methods are leaving a lot to chance, and make it more difficult to assemble and get smooth operation (see the bottom half of figure 3). While we are on the subject of straightness/flatness, again, as a general rule, heat treating racks is problematic. This is especially so with cold-drawn materials. Heat treat-induced warpage and cracking is a fact of life.

Solutions to higher strength requirements can be pre-heat treated material, vacuum hardening, flame hardening, and using special materials. Moore Gear has many years of experience in dealing with high-strength applications.

In these days of escalating steel costs, surcharges, and stretched mill deliveries, it seems incredible that some steel producers are obviously cutting corners on quality and chemistry. Moore Gear is its customers’ greatest advocate in requiring quality materials, quality size, and on-time delivery. A steel executive recently said that we’re hard to work with because we expect the correct quality, quantity, and on-time delivery. We take this as a compliment on our customers’ behalf, because they count on us for those very things.

A basic fact in the gear industry is that the vast majority of the gear rack machines on shop floors are conventional machines that were built in the 1920s, ’30s, and ’40s. At Moore Gear, all of our racks are produced on state of the art CNC machines—the oldest being a 1993 model, and the newest delivered in 2004. There are approximately 12 CNC rack machines available for job work in the United States, and we have five of them. And of the latest state of the art machines, there are only six worldwide, and Moore Gear has the only one in the United States. This assures that our customers will receive the highest quality, on-time delivery, and competitive pricing.

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