GEAR FUNDAMENTALS

Coarse Pitch Gears

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This article discusses briefly some common manufacturing problems relating to coarse pitch gears and their suggested solutions. Most of the discussion will be limited to a low-quantity production environment using universal machine tools.

Material Selection and Heat Treatment

Table I shows common heat treatment methods and some standard grades of material associated with them.

Selection of gear material shape. Once the heat treatment and material have been selected, the starting shape or form of the material is chosen. The shape and size of the finished gear blank will dictate the form of the material to be used, such as hot rolled bar, forged bar, step forging, rolled ring forging, casting, etc. See Figs. 1-5 for some typical coarse gear blanks. The choice is also based on many other factors, such as design requirements, cost, and availability. The material and related details should always be reviewed from a manufacturing point of view. A certain percentage of material must be removed from a hot rolled bar, particularly in the gear tooth area. Excessive material removal from any shape should be followed by stress relieving before finish machining.

Table 1

Heat Treatment Method	***Material***	***Comments***
Through-Hardening	**1040, 4140 4150, 4340**	**Practically any medium-carbon steel can be used.**
Nitriding	**4140, 4340, Nitralloys**	**Any number of other alloys can be nitrided.**
Induction Hardening	**4140, 4150, 4340**	**Any medium-carbon steel can be used.**
Flame Hardening	**4140, 4150, 4340, 4640**	**Any medium-carbon steel can be used.**
Case Carburizing & Hardening	**4620, 8620, 4320, 4820, 3310, 9310**	**Any low-carbon steel can be carburized.**

Correction for distortion in heat treatment. It is normal practice to make some kind of correction of distortions caused by heat treatment. Possible corrections include, a) changing the lead or helix angle in threaded worms and helical gears before heat treatment to compensate for the change after heat treatment; b) altering tooth contact in bevel gears to minimize the effect of change in a hardening process; c) tooth size correction to compensate for changes in heat treatment.

In case of high production, samples are normally checked before and after heat treatment. The changes are recorded and analyzed. The production pieces are then modified to compensate for the predicted heat treatment distortions.

In case of low-quantity production or in a jobbing atmosphere, testing of actual pieces is not feasible. Thus, manufacturing engineering should make a study and provide guidelines for corrections during production to compensate for heat treatment distortions.

"No carb" paint. In many cases carbon removal operations can be effectively reduced or eliminated by the use of no carb paint.

Masking paint for nitrided parts. Masking paint can be used to keep certain areas soft as required by design or for post-machining.

Use of quench press to control distortions. Fig. 6. shows a quench press set up to quench a

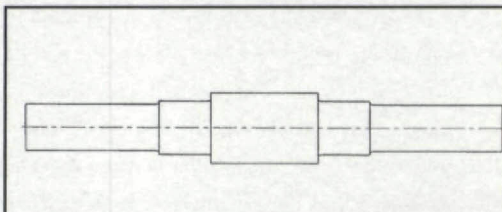

Fig. 1 - Step forging outline.

webbed cylindrical gear. Normally an expanding die is used to keep the part round, and a clamping die to keep it flat. The arrows in Fig. 6 show the suggested path for quenching oil.

Scale removal after hardening. This becomes quite important in certain cases, as scale can have many detrimental effects, including loading up the grinding wheel.

Tool Selection

Customized tools and test pieces offer many ways to enhance gear quality and productivity. For example, they can help to optimize protuberance and grinding allowances for ground gears and correct the amount of radius of teeth tips. But many times, universal tooling is the only choice for various reasons, including economic and time constraints. Below are some suggested strategies to control tooling problems.

Root fillet. Standardize root fillets for all new designs and use them whenever possible. Fig. 7 shows a comparison of standard fillet and full fillet. In most cases, switching from standard to full fillet improves the gear rating. However, there are some special situations where this conversion can cause negative effects, such as insufficient wall thickness between the root of the teeth and the bore.

Topping hobs. Topping hobs should be considered as special hobs, and their use in coarse pitch gears is very limited. Sometimes they can be useful in finishing the outside diameter on the teeth cutting machine along with the rest of the tooth. But this process has not been found to be practical for various reasons, such as time, tool life, and surface finish.

Semi-topping hobs. Semi-topping hobs can be very useful in coarse pitch gears to cut down the deburring time and control the amount of tip radius/chamfer on the tips of teeth. Great care must be taken in the design of semi-topping hobs, since serious damage can be caused by removing an excessive percentage of the active tooth profile.

Multi-thread hobs. Proper use of multi-thread hobs can increase production and reduce both time and tool cost. Concerns to be taken into account while using multi-thread hobs are: number of teeth in the gear vs. number of threads in the hob; total number of teeth in the gear, because a low number of teeth in the gear may not be suitable for multi-thread hobs; quality of the hob; hob resharpening; quality and surface finish limitations obtained with the use of multi-thread hobs.

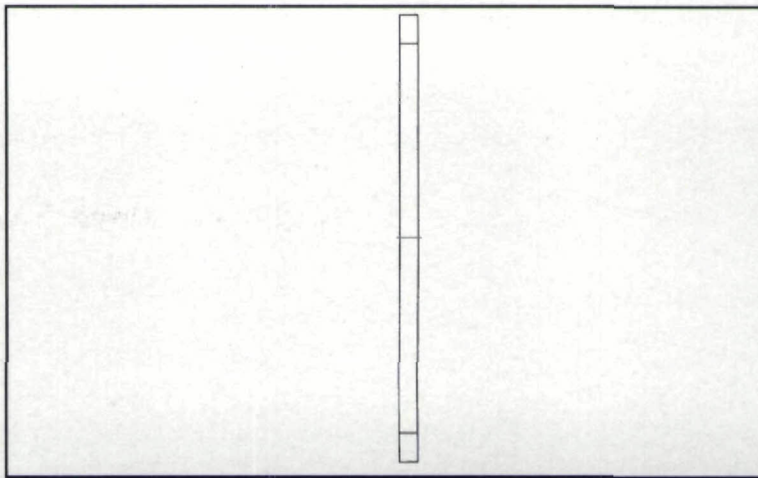

Fig. 2 - Ring forging outline.

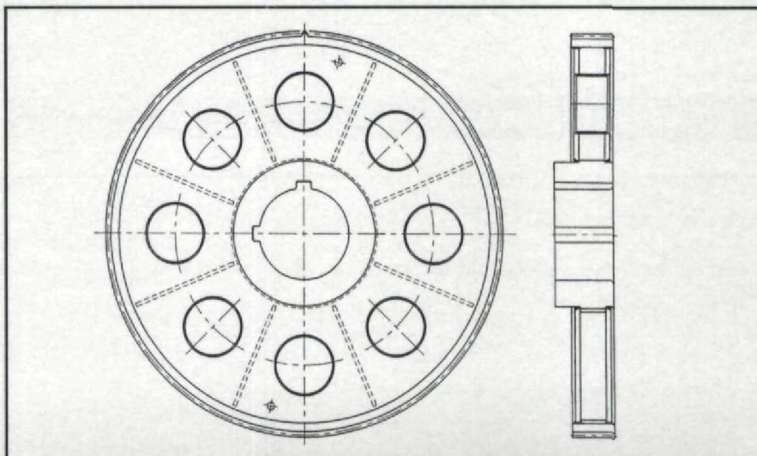

Fig. 3 - Gear weldment.

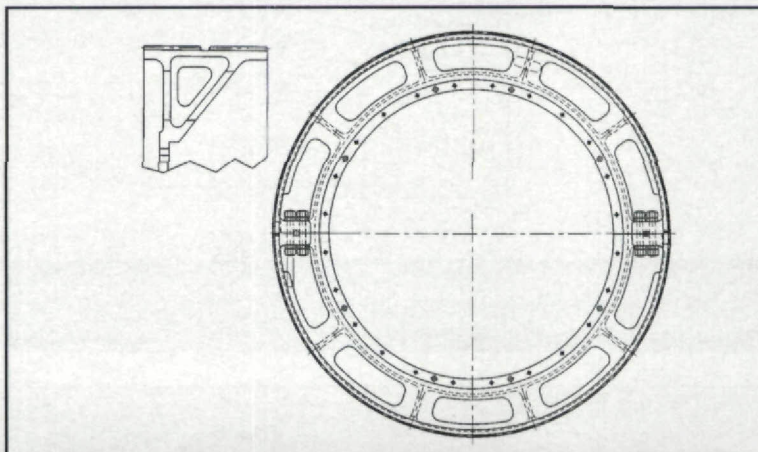

Fig. 4 - Casting (2-piece design).

Grinding allowance. The amount of grinding allowance required for various pitches and sizes should be standardized based on past data and experience and the heat treatment method used. This is a must for ordering the tools, as the amount of grinding allowance effects the tool design.

Protuberance. The correct amount of protu-

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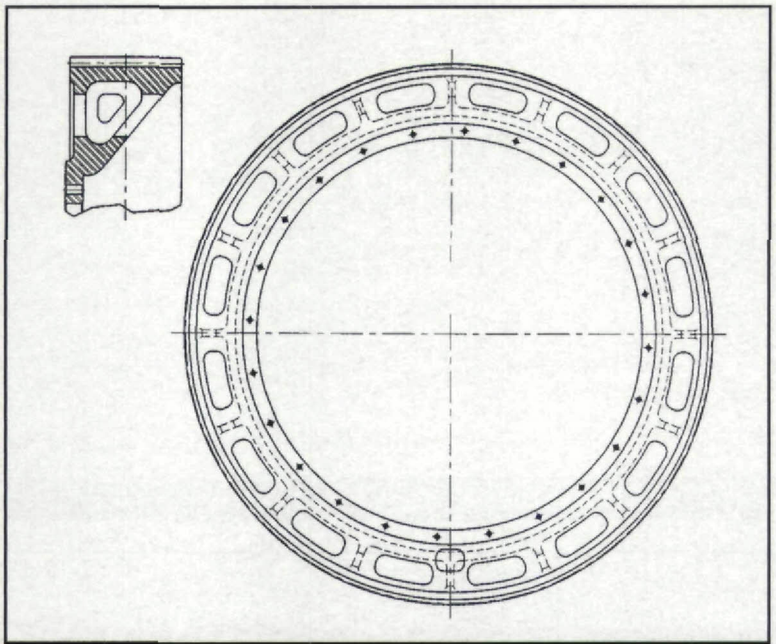

Fig. 5 - Casting (1-piece design).

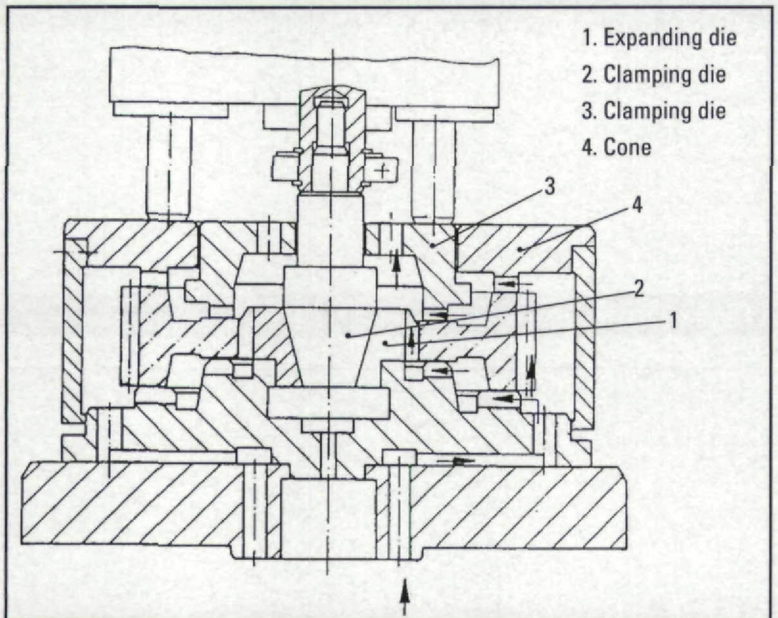

Fig. 6 - Quenching a cylindrical gear with special configuration. (Ref. Klingelnberg quench press.)

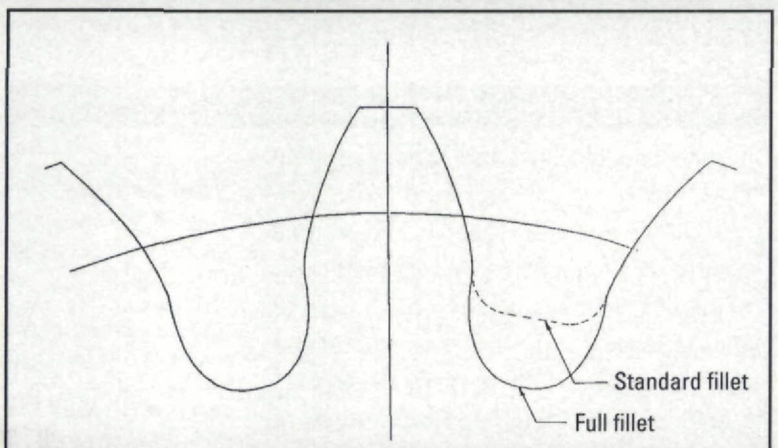

Fig. 7 - Standard vs. full fillet.

berance is very critical for ground and shaved gears. Excessive protuberance can cause an uncleaned profile along the tooth, while insufficient protuberance can cause a grinding step problem. Fig. 8 shows a protuberance tool.

Tool material. Tool material should be chosen very carefully. Fig. 9 shows a comparison of some of the material commonly used for high speed tools.

Tool coating. The use of special cutting tool coatings, such as TiN and TiCN, can help in many ways. For instance, they can reduce tool cost by prolonging tool life and producing better surface finish and lower cutting times by the use of higher feeds and speeds.

Tool resharpening. Tool resharpening is one of the most neglected subjects in gear manufacturing. Poor tool sharpening causes many problems, such as poor profile, premature tool failure, unsatisfactory surface finish, etc. A good tool sharpening program includes updating and maintaining tool sharpening equipment; proper grinding wheels, good sharpening fixtures, and inspection of tools before and after tool sharpening.

Proper care and attention to tool sharpening is very critical in coarse pitch gear manufacturing. It will make an important difference in the performance of the hob and hobbing machine.

Proper storage and record keeping. Careful practice here can eliminate many unnecessary delays and cut down on tool costs.

Teeth Cutting

Gear Blank Hardness. The hardness range of the gear blank at gear cutting primarily depends upon the selected material and the hardening method. Case-carburizing steels rarely cause tool problems at soft cutting because of lower hardness. On the other hand, through-hardened, induction-hardened, and nitrided parts may cause problems, depending on the material and blank hardness. The following are some suggested methods for handling through-hardened gears with hardness values higher than a normal range.

Rotary roughing cutters (with carbide inserts). A rotary roughing cutter with carbide inserts can rough gear teeth with higher hardness in much shorter time than high speed steel tools (hob, rack, or Fellows type). As a matter of fact, roughing with a rotary cutter is very useful for large, coarse pitch gears in any condition. It saves time and lowers the tool cost. The factors to be kept in mind for roughing are using the proper tool for certain DPN and pressure angles; using a machine with a single indexing arrangement; and using proper surface speed and feed for carbide cutters.

Some new, large hobbing machines are being manufactured with the capability of roughing with rotary carbide cutters. Some old hobbing machines can be modified to use this method of roughing.

Roughing annealed blanks. Some higher hardness gears can be roughed in an annealed condition, heat treated to the required hardness, and then finish-machined, including teeth cutting. This method provides uniform hardness throughout the tooth, including the root area. Some very coarse pitch gears are produced this way to achieve proper hardness on the entire tooth. When using this approach, the following factors should be kept in mind: extra operations will be needed for teeth cutting, heat treatment, and finish-machining; and certain gear configurations may cause some additional problems at heat treatment after rough machining and teeth roughing.

Controlling Higher Range of Hardness Values. Usually the hardness of a gear blank is specified as a range. The rating is calculated based on the lower value, while the higher value depends on the normal heat treating standards. Any closing of this range requires an additional tempering cycle, which can possibly cause the hardness to drop below the lower value. But for higher hardness coarse pitch gears, any control on the higher limit will definitely help at teeth cutting, while offsetting any additional cost of heat treatment. Control of the higher hardness limit will also benefit tooth cutting, since high speed steel tools become very inefficient above certain hardness values.

Use of specially designed hobs. Many specially designed hobs, such as rough hobs with positive rake, shear-cut hobs, multi-section hobs, multi-thread hobs, etc. can reduce tool cost and cutting time.

Teeth cutting times. Teeth cutting times can be improved by controlling such items as proper work holding fixture, correct and sufficient cutting tools, properly machined gear blanks, properly sharpened tools, maintained machine tools, regularly trained personnel, well kept coolant system, correct feed and speed, right among of cuts, and resharpening of tool at correct time.

Surface finish. The surface finish of coarse pitch gear teeth depends on many factors, including the method used for teeth cutting, such as hobbing, shaping (Maag or Fellows), or form milling. The following are some important concerns that directly or indirectly effect surface finish:

- Feed and speed at final cut.
- Material for final cut. The correct amount of stock removed in final cut must not be overlooked. Too much or too little stock are both detrimental to surface finish at final cut.
- Sharpened tool before final cut.
- Material hardness and machinability.
- Minimum material removal. Whenever possible it is desirable to remove a minimum amount or no material at all from the roots of teeth during the final cut. One approach is to rough cut teeth with a modified tool that allows little or no material to be removed at final cut. The cutting tool holds a better cutting edge and provides a better surface finish when the tip of the tool does little or no work.

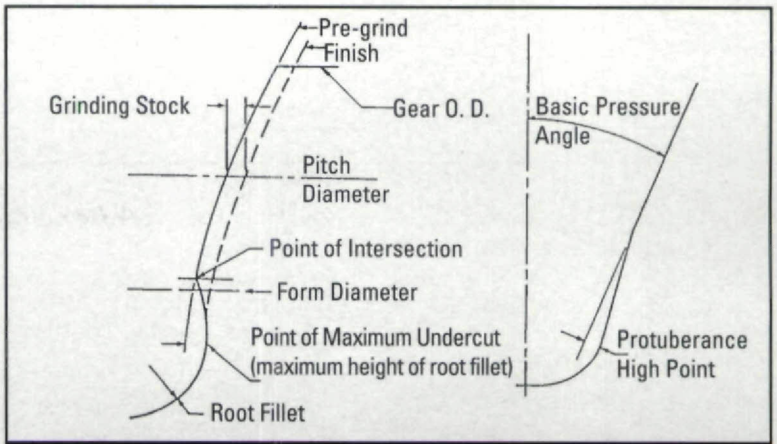

Fig. 8 - Typical protuberance type basic hob tooth form.

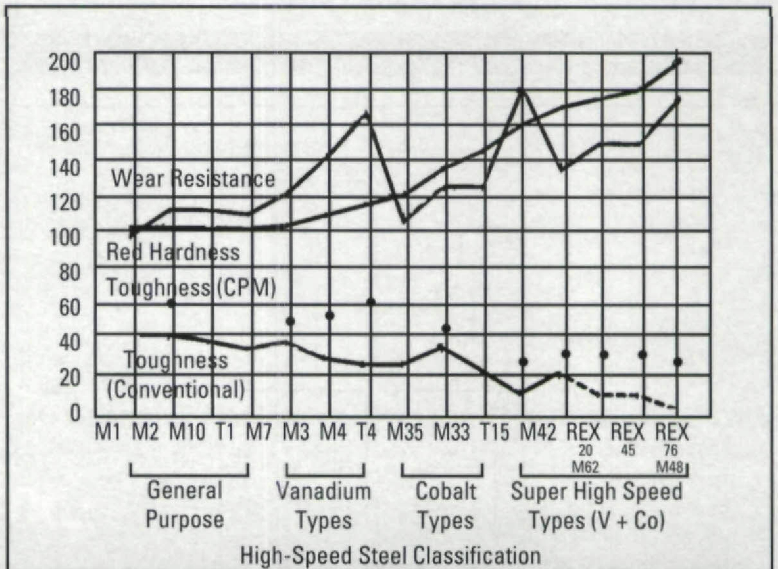

Fig. 9 - High-speed steel comparagraph.

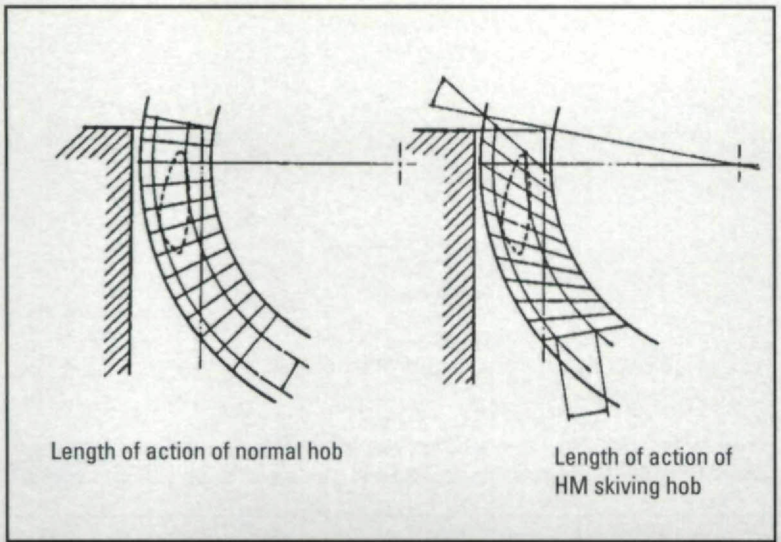

Fig. 10 - Hob skiving.

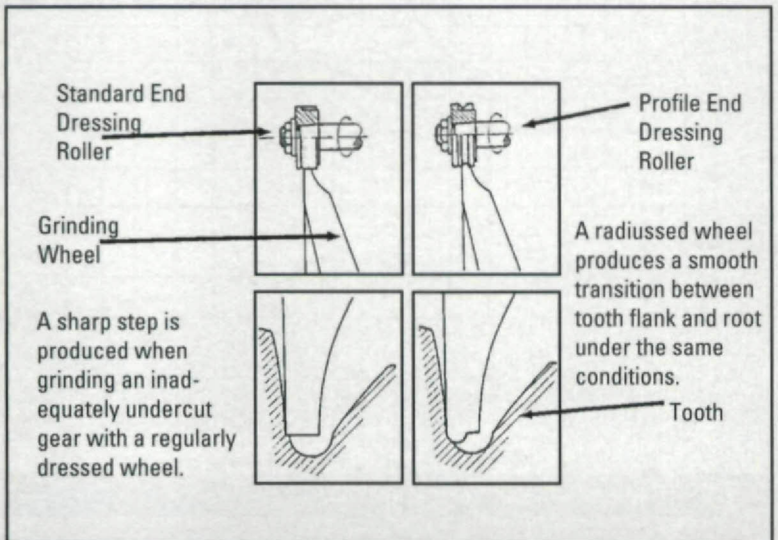

Fig. 11 - End dresser options for saucer wheel grinding machines.

The method of manufacture also effects the tooth surface finish. In the hobbing method, the number of gashes, or flutes, in a hob is a function of size, pitch, and other factors. Coarser pitch hobs normally have fewer gashes than finer pitch hobs. Consequently, finer pitch gears normally have a better tooth finish surface than coarser pitch gears.

Skiving or Hard Cutting

Skiving or hard cutting in hobbing or shaping is a term used to describe the operation in which hardened teeth are roughed or finished using a carbide tipped hob or CBN insert tools. Skiving in hobbing has limitations on quality based on many factors including machine, quality and sharpening of the tool, setup, gear geometry, etc. (See Figs. 10-11.)

Skiving hob sharpening. The carbide skiving hob is normally sharpened using a diamond wheel. Special setups are required at every sharpening to keep the pressure angle constant. A properly sharpened skiving hob is very critical for successful skiving. Improper sharpening can even produce hairline cracks in carbide inserts.

Protuberance and root clearance. Skiving hobs, as well as CBN tools, have been found inefficient in removing metal from roots because of premature chipping of tools. Therefore, proper protuberance and root clearance must be produced at soft teeth cutting prior to heat treatment.

Feeds and speeds. Feed and speed in skiving and hard cutting is important, not only for quality and time, but also for the successful execution of the process itself. Improper feed and speed can cause poor tool life, long machine time, poor quality, and many other problems. These problems can cancel all the advantages of the skiving or hard cutting. Tool suppliers should be contacted for recommended feed and speed values, which later can be optimized for each individual situation.

Skiving as a pregrind operation. Skive hobbing as a pregrind operation can be very helpful in many ways, as discussed in the section on Gear Tooth Grinding. Skiving can reduce the run time on critically loaded tooth grinding machines. In setups with limited grinding capability, skive hobbing can also be advantageous as rough finishing operations for CBN hard cutting.

CBN hard finishing of gears. CBN hard finishing is being used more and more on spiral bevel gears using rotary cutters, as well as on parallel axis gears using shaper type machines (rack type). This method provides gear teeth with the quality and surface finish of grinding without the possibility of metallurgical damage. This method also provides a means to finish larger gears which will not fit on a grinding machine. For example, gears which were originally designed as through-hardened, since no grinding capacity was available for finishing, can be case-hardened and hard-finished. Thus, the gear set rating is increased considerably without increasing the size of the set.

Gear Tooth Grinding

Gear grinding steps. Grinding steps in tooth fillets are very detrimental and have various causes. They act as stress risers and also reduce the critical case depth in tooth fillets. Any subsequent work performed to remove the steps raises the cost and can cause other problems. Here are some suggested approaches to eliminate or reduce the steps in tooth fillet.

• Always use a hob with proper protuberance, thickness, blend angle, fillet radius, etc.

• Use the correct amount of grinding allowance on tooth thickness at cutting.

• Grind the tooth flank to proper depth. Define and use the point of maximum undercut during grinding setup.

• Continuously train and educate personnel.

• Monitor and resolve problems by immediate attention.

Sometimes it will be quite difficult to avoid steps completely, because of excessive distortion at heat treatment, use of improper tools, excessive grinding allowance, etc. In such cases, use of a grinding wheel with tip radius can avoid sharp corners in grinding steps. The amount of radius can be selected on the basis of DPN, grinding machine, and all other factors. The same approach can be used in conical wheel grinding machines.

Gear grinding cracks. Gear grinding cracks usually indicate that there is a process control problem, either in heat treatment or gear grinding, or both. The correct amount of case carbon content is very critical, because an insufficient amount can cause low hardness problems; whereas, an excessive case carbon content can cause the presence of retained austenite. The grinding process generates pressure and heat, which causes transformation. Retained austenite transformation at grinding is considered a source of surface tempering or cracks or both.

Free carbides or carbide networks in case structure are another side effect of excessive case carbon content. Excessive hardness of the material (free carbides) can cause localized overheating. Overheating during the grinding results in surface tempering or cracks or both.

Heat treatment operations usually result in some film on the surface of heat treated parts. This scale must be removed before grinding, as it tends to load the grinding wheel. Surface oxidation in heat treatment produces a thin layer of decarburized and soft material on teeth flanks. This material loads up the grinding wheel, causing overheating, leading to surface tempering or cracks or both.

Excessive tooth distortions in an irregular pattern make it difficult for machine operators to locate the highest point on the gear tooth surface. If the grinding cut is not started at this point, excessive amounts of material will be removed during the cut from high points. Excessive cuts will generate overheating and can lead to cracking or surface tempering or both. This problem can be handled easily by the machine operator on a machine with threaded wheels and continuous indexing.

Gear grinding variables. The variables in gear grinding operations are the gear grinding machine, the grinding wheel, the coolant, in the case of wet grinding, and the grinding machine setup. Any problem with one or more variables can lead to various problems, including cracks on teeth. As discussed before, excessive heating at any point in the grinding operation can lead to surface tempering or grinding cracks or both. This overheating can be caused by a combination of factors, such as malfunction of the gear grinding machine, use of an improper grinding wheel, unsuitable coolant, improper positioning of coolant nozzle, or an excessive amount of cut or material removal.

Gear grinding cost. In a jobbing or low-batch production atmosphere, gear grinding time and, consequently, cost is an important matter. The time estimation is normally based on many factors in grinding, such as the number of teeth, DPB, helix angle, face, material, grinding allowance, quality, method, and machine. The final time estimate is then modified on the basis of past experience. Somehow the estimated time usually falls short of actual time. In the current competitive world, the gear grinding cost has to be maintained at a reasonable level. Below are some suggested approaches;

• Setup preparation cannot be overemphasized in a low-production atmosphere. It is good practice to have more than one item ready for the grinding machine. In case something goes wrong at the last minute with the first item in the line, the next in line can be started without excessive idle time.

• Heat treatment distortions and inadequate manufacturing process control will deliver gears with high inaccuracies to gear grinding. This will increase grinding time. Therefore, good control during the heat treatment and manufacturing processes will cut grinding times, reduce the number of scrapped parts, and enhance quality.

• Good preventive maintenance of gear grinding machines will keep downtime to a minimum.

• Training and education of personnel is quite critical and must not be overlooked.

• Use of skiving hobs can be very helpful in many ways. For instance, skiving can remove most of the distortions caused by heat treatment and present a gear for tooth grinding with limited grind allowance. This will reduce grinding time, remove any heat treatment scale or decarburized and soft layers of material from teeth flanks, and reduce the possibility of the surface tempering or grinding cracks or both.

Stress relieving after tooth grinding. A stress relieving operation after tooth grinding is highly desirable in all critical applications. The stress relieving minimizes the possibility of latent grinding cracks. Latent grinding cracks are the cracks that develop in the storage or early period of use. The typical stress relieving for case-carburized and hardened parts is around 320° F for four hours, which can be further refined for every application. The stress relieving must be carried out as soon as possible after tooth grinding, as any excessively delayed stress relieving may be too late.

Grinding allowance at tooth cutting. Excessive grinding allowance causes many problems. To avoid excessive material left at teeth cutting, all cutting personnel should be trained, parts must be checked, and sized recorded after teeth cutting.

Handling of gears with grinding cracks. Any part with severe grinding cracks or surface tempering cannot be salvaged. The suggested approach for parts with minor problems include stress relieving, regrinding to remove cracks, checking final tooth sizes and remaining case depth, and reporting all findings to the engineering department for final disposition.

Gears with close tooth thickness tolerances. Many applications need close tooth tolerances. A practical approach is to keep an approved master gear in the same environment as the gears being ground and compare sizes. For the most part, the first piece of a batch can be used as a master after complete inspection.

Miscellaneous

Shaving, honing, and lapping of coarse pitch gears. Theoretically, any gear can be shaved or honed as long as a tool is available. In practice, usually shaving and honing is associated with parallel axes gears. Whereas lapping can be used for any kind of gear where either a mate or lap is available.

Increase in gear rating due to high material hardness vs. manufacturing problems. Allowable bending and contact stresses depend upon the hardness, the quality, and grade of material. higher hardness allows higher allowable stresses, providing a higher rating or smaller gear set for any condition. In manufacturing, high hardness above a certain range becomes a problem. The design and engineering group must work very closely with manufacturing to keep this situation under control. At a certain point, it is better to have a larger gear than a hard one because the manufacturing cost at impractical hardness values will outweigh the cost due to an increase in size. Also manufacturing must be reasonable and innovative in handling the harder gears, since lowering the hardness too much will make the design uneconomical due to the increase in size.

Machining of gears after heat treatment. Finish machining of gears after heat treatment is very critical and must not be overlooked or neglected. Gear teeth can be checked for runout in the plane of rotation on a turning or grinding machine with a roller in teeth, but there is no easy way to check in an axial plane. Quite often, overcorrections are made in one place, causing extra problems in the other place. One effective approach is to indicate proof surfaces (in both planes), which were created in machining before teeth cutting and used in teeth cutting.

Another very effective method is to turn or grind proof surfaces after hardening and check gear teeth for runout and lead. Then finish machine the gear bore and faces of shaft journals after making corrections based on runout and lead charts. The above method is effective, but needs two extra operations and longer manufacturing cycle. Also, it is ineffective when a gear has irregular distortions, such as a tapered length or oval-shaped diameter. ■

References:

Loy, William E. "Hard Gear Processing with Azumi Skiving Hobs." AGMA Technical Meeting, October, 1982.

Sharma, Yogi. "Gear Grinding Fundamentals." S.M.E. Gear Clinic, November, 1988.

Acknowledgement: *Presented at the SME Advanced Gear Clinic, October 20-22, 1992, Dearborn, MI. Reprinted with permission.*