

## Harshwardhan Gupta's Design Tips-20

### Gears

Symbolically, gears are the most 'mechanical' of all things engineering, so much so that almost all engineering colleges and many companies have a gear in their logo! The Germans more accurately call them 'zahnraden' or 'toothed wheels', which is exactly what they are. I won't go into types of gears and other information that can easily be obtained by an average engineer, or go into high fundas of gearbox design.

As a designer, I divide gears into two groups: one transmitting power, one transmitting motion! Well, obviously one does the other too, but the former are carefully designed and put into well-sealed gearboxes, and live happily ever after with their spouse in their warm, weatherproofed house. The other poor guys are casually treated and left out in the open, gnashing and grinding and chattering their teeth! The former are usually bought from a gearbox maker and the latter are usually designed and manufactured / vendored by the machine-builder.

Problems with purchased gearboxes usually end up in obstinate arguments. If they have been bought with the motor as a drive package, the problems usually start with the motor. If a variable-frequency drive has been put and the motor is continuously run at low RPMs and good load, it burns out because cooling is not adequate. Best way out is to provide external cooling. Very frequent reversals also result in burnouts. Clogged fins in dusty environs also lead to burnouts. Wrong connections, a welding set on the same bus as the VFD, are all causes for heart... I mean, motor burn. Many people don't realize that a VFD is a piece of fine electronics, and you can't abuse it the way you can abuse conventional motor switchgear – just the way you cannot abuse a computer the way you can abuse a toaster.

Failures of drive packages on the gearbox side are more often than not results of contamination, leakages, wrong lubricants, overloads, vibrating loads, electric current passing through the gearbox, mounting screw-ups like misalignment, etc... Too much radial load (often by an over-tightened / over-designed v-belt), or too great a radial load overhang – pulley not being as near to the output side bearing as it could be / should be (Squeeze it inward to the very last possible millimeter!) as possible, commonly results in shaft breakages. This breakage usually takes place just inside the shaft-side bearing, not outside it. This is inevitable. If the gearbox is drive by a V-belt, this usually happens to the motor. Going into battle with the supplier is not going to solve this.

Wormshaft / wormwheel teeth get very badly chewed up by overloads, wrong mounting, leaking oils, wrong type lubricants, blah blah... as the manufacturers will tell you. One factor no manufacturer will talk about is the presence of loose sand (if it is a cast-iron box) and / or metal chips in brand-new factory-fresh gearboxes. I have often come across this personally in the best of makes (the aluminium die-cast ones are better in this aspect). This stuff gets between the teeth, and merrily wears them out. The debris thus produced only accelerates the process! *Ghabraiye nahin, ilaaj hum bataate hain!* Dismantle that brand-new or used gearbox completely, wash it out with mineral turpentine, and reassemble. Let the sludge settle and feel for grit in the bottom of the pan for yourself! You probably just saved more than a whole year's subscription to IPF. If a few grains of fine sand are present, they will embed themselves into the softer wormwheel, and endlessly grind away the harder wormshaft – the exact process of lapping. If chips are present, they will eat away the wormwheel. *Safai hi khudai hai* – cleanliness is next to godliness!

So, we come to their poor cousins in the cold, sometimes naked, sometimes behind bars in a *jaali*, some living in a bottomless tin shed cryptically called "gear guard left" on the drawing. They occasionally get a starvation diet of oil or grease; else go hungry. Lets clear some of the common confusion about them.

1. Involute gear action is not pure rolling. Before and after the pitch line, there is a very small

- amount of sliding.
2. As number of teeth decrease in a spur gear, the tooth root goes on thinning, and soon the tooth takes the shape of a classic Coca-cola bottle, rather than the healthy silhouette of a Sumo wrestler. To counter this, you should apply 'correction'. This essentially makes the teeth stronger. Correction is simply cutting same number of teeth to the same tooth depth on a larger or smaller than normal blank with the very same hobbing machine settings. For example, the 'normal' pinion of a 2 module, 15-tooth gear will have a pitch diameter of 30mm, and an OD or addendum dia of 34mm. If you increase this by one module per side, you end up with a gear of 38mm OD, and this is called a correction factor of +1 (module). If this OD is 37mm, this factor will be +0.75. 36mm will be +0.5. 32mm will be -0.5 and so on. Pinions smaller than 17 teeth need a positive correction. Now if the center distance is standard, pinion has a +0.75 correction and the mating gear is 60-tooth, then it must have a -0.75 correction, and its OD will then be 121mm. Negative correction in a gear with many teeth does not alter the profile detrimentally. With +1 (less with more teeth) correction, you can safely go down to 10 teeth. Below that, down to 3 teeth, is the domain of super-specialization.
  3. There is no need to over-cut gears to get sufficient backlash, and vice versa. No need to increase CD to do the same, too!
  4. And proper depth (exactly 2 times module) must engage in ALL situations – absolutely no exceptions here! I have seen too many insufficiently engaged gears – this is direct invitation to trouble. You did everything by the book and still have engagement problems? Calculate and check over-pin diameters. Span gauging with a disk-type micrometer is very helpful but you must be able to make the complicated calculations.
  5. You can mate positively corrected (enlarged) pinions with uncorrected gears if you adjust the center distance accordingly. You can mate two positively corrected pinions too with increased CD.
  6. Helical gears are not necessarily less noisy. Properly made and mounted spur gears can be quite silent too.
  7. Avoid designing gear mounts with adjustable CD, like putting the two shafts in sideways-adjustable pillow (Plummer) blocks. Murphy's Law applies here.
  8. Stay away from cutting gears on milling machines with form cutters and indexing heads. Would you get your trousers stitched from a ladies' tailor to save money?
  9. It is not at all a healthy idea to deep-mesh gears to avoid backlash. If you need backlash-free operation (say for a servo-drive), use timing belts instead. I have designed and run 3-stage, 30:1 timing belt servo-drives. With demonstrably zero backlash! Even higher reductions are possible.
  10. Herringbone gears are only used in gigantic gearboxes. Otherwise, they are just a red herring. Every young machine designer wants to design one. Don't even think about them.
  11. You can mate helical gears with worms for light loads, the helix angle being the helical angle of the worm thread, both having same hand, just as in wormwheels. Nylon helical gears mated with steel worms work very well – open a Lucas TVS wiper motor and see for yourself. Toys often have sheet-metal spur gears happily mating with worms.
  12. You can even create a 'cross-helical' right-angle drive with two helical gears of the same hand, and it is not so sensitive to CD errors. See the speedometer drive of a motorbike.
  13. Avoid straight bevels. They are a nuisance to make one-off, prone to design and manufacturing mistakes, sensitive to mounting rigidity and demand great accuracy, and are noisy even at 100 rpm! Pick up new standard hypoids or spiral bevels from the auto spare market and use them. Preferably, get their housing too – you will need it to accurately measure the cone-center-to-base distance, centerline offsets, etc.
  14. Planetary gears require very accurate gears and even more accurate planet carriers. They must be enclosed properly. If 3 planets are

used, all numbers-of-teeth must be divisible by 3; if 4, then by 4 – you can't break this rule. Internal gear ring, if not very large, can be made by wirecut. Be very clear in your mind about who is driving whom, their directions of motion, torque reactions, bearing loads and reduction ratios.

I have seen a big company sell pneumatic motors with planetary reducers – four identical single planetary cartridges in series, one driving the other – who insisted that since the single stage reduction ratio was 3, the torque rating of the drive was  $3 \times 3 \times 3 \times 3$  (81) times that of the basic air motor! The problem came to me when the tiny little output shaft was repeatedly breaking right inside the output end bearing during trials, when stalled after tightening a chuck. The company repeatedly sent its application engineers to look into the complaint, and they steadfastly refused to acknowledge that as the torque multiplied in each stage, the dimensions of each stage's components had to be appropriately scaled up too, to keep the stress within limits. They tried very hard blaming it on every possible or impossible external cause. They even brought back an assembly where the last stage gear width was doubled, which also promptly broke, then finally "referred the matter" to their silent, invisible design department; at which point I advised the client to replace the whole setup with a standard 3-phase torque-motor + helical gearbox drive, as you can stall a torque motor just the way you can stall an air motor.

15. Spur gears, which are not deeply chamfered on a proper tooth-chamfering machine, will NOT slide into each other axially either while moving or even when stationary. Chamfering on lathe does not solve the problem. If sliding is needed, and if you can't get tooth-chamfered gears, use a constant-mesh design with trapezoidal dog-clutches.
16. Harder gears can tolerate more contact stresses, so overall sizes can be reduced if you harden. Pinion must be harder than the gear. If the stresses are high, do a dye-penetration test for cracks.
17. Very high reduction ratios can be obtained by

many ingenious designs, but unless you know what you are doing, leave it to the experts. And resist the temptation of constructing a harmonic drive.

18. Before you issue production drawings and write the process sheet, talk to your hobber whether he will do that job with a topping hob or a non-topping hob. As the name suggests, topping hob shaves the OD too. Non-topping hob leaves it alone. So your blank should have machining allowance if a topping hob is going to be used, and should be made to final size if the hob is non-topping.
19. Gear arrangements are one area where one can inadvertently get into an impossible-to-assemble design. So, after you detail, work out the assembly sequence or call the assembly guy over to get his approval.
20. Not all gears carry heavy loads, nor all run continuously. Some only work a bit for a few seconds. So keep the materials, processes and design sensible and don't go overboard, nor cut too many corners.
21. If gears are failing prematurely, have a good look at the failed gears and try to figure out precisely why they have failed. If you don't know how to, consult appropriate books, etc.
22. If all teeth are showing signs of distress, like pitting, scuffing or heavy wear, chances are the bearings are finished too! *Swasth daton ke liye hamesha synthetic grease with EP (extreme pressure) additives istemaal keejiye!*
23. If a gear, pulley, etc. is stuck on a shaft, and you can't put a proper puller to it, but can only pry it out with a lever bar, then pry it out with two identical lever bars (or two identical screwdrivers) put opposite (mirroring) each other, and with a jerk, force it out as symmetrically as possible, and see the magic. *Arre, nikal gaya Sir, nikal gaya!*

*Dekho kaise gear pe gear, gear pe gear badal raha hai, phir bhi uski gaadi aage hi nahin badhti!*

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