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Harshwardhan Gupta's Design Tips–1

Assembly with Adhesives

Industrial adhesives have come a long way from being used to paste stickers in aircraft toilets. Did you know that almost all parts of the Boeing 747-400 wings are assembled with industrial adhesives? These wing assemblies have proven themselves to be more reliable than the older ones with mechanical fasteners. Industrial adhesives have been finding increasing uses for the last 3 decades. They have grown from the ubiquitous Araldite and M-seal to hundreds of varieties for specific purposes.

Most important, if used properly, they can replace more expensive parts and processes, and save money for you. Many adhesives may appear "expensive" to a first-time user, as they are rather expensive on a per-gram basis, but you often need just a drop or two to do the job. Almost all adhesives are vibration resistant, and will hold fast even under severe vibrations. Many are so strong that they will not give way before the parts themselves are destroyed. In this piece I have restricted myself to joining adhesives, and have not covered compounds used for sealing – they are a family unto themselves.

Industrial adhesives can be classified into the following major categories:

1. **Anaerobic Adhesives:** These remain liquid in air indefinitely, but harden as soon as air is excluded – as in a push-fit assembly. These do an excellent job of producing a press-fit in round parts, and are fairly useless in joining large flat surfaces. To achieve a good press-fit; a close sliding fit should be specified on the parts, not a press fit. A well designed and a well-made joint can REALLY be as strong as a keyway or a shrink-fit.
2. **Epoxy and other 2-component adhesives:** These are the strongest of the lot, but they need time to set. Most of the viscous 2-component liquid epoxies first become absolutely fluid as they set, then become solid, so it should be kept in mind that unless restrained, the adhesive will leak out before setting – or the parts might move. Though epoxy putties are often used to fill up blowholes in castings, it is not a good practice to use defective parts in new machines.
3. **Solvent-based adhesives:** These have a limited strength, compared to anaerobic or epoxy adhesives. They should be used in such a way that the solvent has time and breathing space to evaporate. The rubber-based ones are a rather unusual – they have to be applied on BOTH surfaces, and have to be almost dry BEFORE pasting. Using them is a one-shot job; and once even a small portion is pasted, it is impossible to separate and re-position the parts if you have made a mistake. Variants of solvent-based glues are often used as sticker glues with a release paper.
4. **Room Temperature Vulcanizing Rubbers (RTVs):** These cure in the air once they are out of the squeeze-tube. They are often used to hold small parts and fasteners in place, especially under vibrations. Extremely effective and can really reduce service calls originating from assemblies long under vibrations coming apart, and save costs in locking fasteners like spring washers, etc.
5. **Instant Glues:** These are cyanoacrylate-based glues. They cure within a few seconds by absorbing moisture from surrounding air, once applied. They are not very strong, and should be used only where allowing setting time is not possible.
6. **Hot-melt adhesives:** These need a complex melting system to apply, but are one of the cheapest and extremely strong adhesives. They gain full strength within seconds - as soon as the little dab is cooled. They can be used in assembly lines and can replace mechanical fasteners.

Besides these, there are ever-newer types making their appearances every day.

Keep the following points in mind while designing with; and while using adhesives:

1. CLEAN, REALLY CLEAN the surfaces to be joined with a strong solvent like trichloroethylene, acetone (but not nail-polish remover) or NC thinner. Do NOT use kerosene or common thinner to clean, as these may leave a film of oil and not allow the adhesive to bond with the surface. Clean plastic parts by washing with detergent and drying thoroughly. Ensure good ventilation, as solvent vapors are toxic.
2. It is a good idea to test the cleaning solvent by evaporating a few drops on a mirror to check that it does not leave oily residues behind.
3. Use a freshly WASHED dry cloth for cleaning. Most cotton waste and/or commercially available rags are full of oil themselves even if they are fresh.
4. With rolling bearings, etc., clean ONLY the surfaces to be joined, not the whole bearing. If you do, then immediately lubricate the whole bearing again after the adhesive sets.
5. Follow the instructions on the pack to the letter. Do not invent your own homegrown ways.
6. Make full preparations to do the job in one shot. These are not mechanical fasteners that can be undone easily if you make a mistake.
7. If you apply the adhesive in the bore, the excess will come out from the far end. If you apply the adhesive on the shaft, the excess will come out from the front end. Decide beforehand where you will have better access to wipe the excess glue, and work accordingly.
8. Just as in painting, wherever possible, you can use masking to prevent adhesives going into wrong places.
9. Use appropriate solvents for ungluing the (metal) parts; do not try to tear them apart. Ask the manufacturer for the type to be used.
10. You can design out mechanical fasteners, and save space, material, fastener costs and assembly time. Adhesives often simplify a complex fastening assembly.
11. With some lateral thinking, you can even make part-assembly adhesives play the role of static seals.
12. Look beyond the price on the carton. Even if you are a small manufacturer, you can still benefit and save money by using new adhesives.

Do grow out of the tendency to nonetheless use mechanical fasteners with the glue, "just to be safe"! Learn to trust adhesives and you will never come unstuck! Happy gluing!

Next Month: Timing Belt Drives

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Harshwardhan Gupta's Design Tips–2

Timing Belt Drives

We still see continuing use of gears and roller chains, where timing belts could do the job much more easily, cheaply and elegantly. Manufacturers' catalogues are easily available, and much information is available on the net too. Timing belts are also known as toothed belts.

Timing belts started with a trapezoidal shape of teeth, known as the Powergrip series. These then gave way to HTD belts, which can transmit much higher power for a given size. Many workshops with hobbing facilities also carry hobs for cutting standard timing belt teeth.

One reason for the limited popularity of the timing belt drives is that they are quite unforgiving, and they cannot easily be made and put together by uneducated fitters. Investing once in a scientific design and manufacturing will save more money than you can believe.

The advantages of timing belts over belts, gears and roller chains are:

1. Absolutely positive drive compared to flat, v or poly-v-belts (erroneously called toothed belts. Many variable-speed belts and toothed V-belts are also mistakenly called toothed belts). This enables exact speed ratios, impossible to achieve with belts.
2. Much lower cost compared to gears or silent chains. Almost same overall cost compared to a good v-belt drive or a high-speed chain drive.
3. Multi-stage reductions are easily possible. I have successfully designed and made backlash-free drives of 1:30 reduction – and incredibly cheap for a zero backlash drive.
4. No lubrication required whatsoever.
5. No idlers or tightening arrangement required. The drive can easily be designed with fixed center-distances, as unlike V-belts, timing belts DO NOT stretch during their lifetime. Some special grades of HTD belts do not stretch at all even during mounting – these are used in drives where position control is required within a micron.
6. Virtually noiseless and clean in operation. Good for food and pharma machines.
7. Backlash-free, so ideal for motions that go back and forth, like servo-drives, or even mechanical mechanisms.
8. Smaller bearings can be used, as the belt tension on the slack side is much lesser than plain belts.
9. Unlike for gears or high-speed chains, no drive housing required.
10. Replacement cost is low, as pulleys don't wear out. Belts have a long life and are quite cheap nowadays.

Keep in mind these points while designing timing belt drives:

1. Use HTD belts: the overall drive cost will be the least.
2. Shrouds are required only on the smaller pulley if the drive is between two horizontal shafts. Shrouds should be put on the larger pulley if the drive is between two vertical shafts. (Shrouds are the two side flanges to prevent the belt from running off the pulleys.
3. Belts are available only in selected whole numbers of pitches. Check with the supplier before designing the drive.
4. Make the pulleys (especially the larger one) in aluminium, maybe with a steel hub if the key load is more than what aluminium can take.
5. Center Distance should be calculated backwards by first fixing the belt-length, not by the usual flat-belt length from center-distance formula.
6. Follow the sizing procedure given in the manufacturers' manuals to the letter. Do not oversize the belt further.

7. The shroud OD should just be level with, or a little more than the outer surface of the belt.
8. The inside edge of the shroud MUST be well rounded.
9. Understand that unlike gears, the Pitch Circle Diameter of the timing pulley is MORE than the outer diameter.

Watch out for these points while making timing pulleys:

1. Depending on whether the available teeth-cutting hob is a topping hob or a non-topping hob, make the pulley blanks (respectively) more or equal to the exactly calculated outer diameter.
2. Do not try to somehow get that belt profile cut into the pulley - with a crude fly cutter on a milling machine, or a homemade hob, for example. Go to a workshop that has a proper hob, and get it hobbed by a skilled operator.
3. Do not over- or undercut the pulleys ever by fraction of a millimeter. Such pulleys will either not assemble right, or will chew up the belt in no time, and no one will be able to pinpoint the fault.
4. Bolt, glue, rivet or stake the shrouds onto the pulleys. For heavy belts and big pulleys, use fasteners, as one of the shrouds will have to be removed to put the belt onto the pulleys.
5. Do not plate or paint the teeth. Blackodise steel pulleys. Aluminium pulleys don't need any treatment. Self-anodizing can be done for longer life and aesthetic reasons. Never ever buff the teeth.

Take these precautions while assembling timing belt drives:

1. First of all, wrap the (HTD) belt on the pulley and check that no light is visible through the teeth. If there are gaps, something is seriously wrong. First check if the belt is not some special profile instead of the usual HTD. There are some low-cost-low-power special profiles available, which are not suitable for normal applications. If the belt is right, then the teeth are wrong – reject that pulley.
2. Keep those shafts parallel! And I mean parallel. The best way to ruin a timing belt is to not to have the two shafts parallel, so the belt rubs against one of the shrouds and soon starts to scuff.
3. If the CD is fixed, put the belt into the shrouded pulley first, then haul it into the other pulley by rotating the pulley with the belt partially wrapped around it. For heavy drives, remove one of the shrouds and then assemble same way. If the CD is variable, do not over-tighten the belt. The tension should just be sufficient to take up the slack. If the belt is whipping or vibrating sideways, it is too loose, and both belt and pulleys will be ruined very quickly.
4. Do provide proper guards as you would for any rotating machinery. Do not let oil drip onto the belt. It can severely damage the material. And obviously, don't let metal chips or foreign objects, sand or process material fall into the belts.
5. Timing belts have a great deal longer life than v-belts. If properly designed and mounted, they can actually outlive every other drive element – belts, chains, gears, bearings, except maybe the machine frame! So don't really bother to keep spares, except for mental satisfaction.

As I said, timing belt drives are unforgiving to careless users and corner-cutters. Look away for too long, maybe at your bank statement, and the timing belt will whip you. Time to tighten your belts!

Next Month: Saving Weight

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Harshwardhan Gupta's Design Tips–3

Saving On Weight

The old engineering joke goes that since the (Soviet) Russians had no market economy, and therefore no real costing departments, they simply sold their machinery by weight, and so they always designed heavy, heavier and heaviest machines.

Are we any different? From what I see around, not really! We take our cues from the Boiler Regulations, Elevator Safety Codes, (where over-design *is* required) and from really old machine design textbooks. Play safe - our mothers tell us. Invest safe - our fathers tell us. And design safe - our engineering professors tell us. So we play Very Safe, Much Safer and Absolutely Safest. Not only that, in most Indian languages, the word for better quality literally means 'heavy'! But safety, or quality, has absolutely nothing to do with weight!

No wonder our efforts to build a Light Combat Aircraft can barely take off the ground. We still see the heavier-is-better attitude among our machine users and even general public. This is old dinosaur-type baggage; and faster we shed it, lighter we all will feel, and faster we will evolve as an engineering nation.

Weight is no guarantee for better performance, or better quality, or a better design. Here are some Do's and Don'ts:

1. We often misjudge the strength and modulus of materials, and over-design everything as a routine. This kind of unthinking over-design results in unnecessarily heavy and unwieldy, and sometimes slow-because-of-heavy-inertia machines. Today, one can easily model the part in 3D in any of the popular CAD packages, and do a finite-element stress-strain analysis to arrive at the optimum. These analyses are commonly available as a service by various consultants and agencies. Even this is not necessary if the designer has a good judgment of a material's strengths.
2. By keeping more space between parts when less will do, results in a bulkier and large machine, and therefore a heavier machine. Very often, designers keep 20-30 mm space between moving parts, where even 1 mm is sufficient. This is just lack of confidence in their own detailing.
3. We also routinely keep everything adjustable. This often results in a heavier design. It is wasteful and not necessary.
4. Using heavy external covers and seals for bearings, when off-the-shelf sealed rolling bearings could directly be used. This is a leaf taken from railways and earthmovers.
5. In similar vein, designing oversized round flanges too results in a heavier design. Few designers realize that in most cases, any flange material outside the PCD is useless, so they may as well reduce the PCD to the minimum, then reduce the OD to the minimum, and have an equally strong but lighter design.
6. The same goes for using heavy sections for press- or shrink-fitting, where modern industrial adhesives could be used easily and safely and heavy sections could be avoided. (See Design tips #1, November 2002)
7. Many of our well-qualified machine designers work in the machine-tool industry, where heavy castings are absolutely necessary to achieve rigidity, sustained accuracies to microns, vibration absorption. When they shift to other industries, many unfortunately bring this baggage into their new design office. High-speed packaging machines, high-performance piece-handling systems, etc., do not need such high rigidity, and can be designed much lighter.
8. Where torsional rigidity is required, a closed section (rectangular, square or round tubes) is many times stronger than an open section (beams, channels, angles) of the same weight-per-meter.
9. Many machine frames (not machine-tool frames) can be made in light sheet metal with

some insightful designing. I have redesigned machines where I brought the frame weight down from 850 Kg to 120 Kg, and actually ended up having a *cheaper* and *more* rigid frame.

10. When you change over from cast-iron to steel sections or steel plate construction, you can make the part much lighter, as the cast-iron's ruling section (minimum thickness) was decided by the (molten) metal flow limitations, not by strength.
11. Making a sheet metal structure curved (like a cylinder), especially curved in two axes (like a dome) immediately results in enormous rigidity, so the sheet thickness can be brought down. In other words, a cylindrical box of sheet metal can support far more weight than a square box. A modern car is a perfect example of this concept.
12. Sheet-metal hat-sections welded to flat sheets make for very strong light-weight structures. Just look at the underside of a modern car's bonnet for proof. Same goes for the car body too.
13. Another sure-fire way to reduce weight, and costs, is to judiciously estimate the real power required to drive the machine. Does that cute little conveyor really need a 1HP motor? Does that packaging machine need a fat 3HP motor to drive it? Look for areas where power is being wasted. Fix those, then actually try the machine with a motor of 1/4th the original power rating. I can confidently tell you that in 95% cases, it will run beautifully in all conditions. Now you can redesign the drives, shafts, couplings, gearboxes, bearings, etc. for that reduced transmitted power and make the whole machine substantially lighter.
14. Using a more expensive but far stronger material (or a material with a higher modulus) combined with good design can actually save money. Do think on those lines too.

Do not listen to old wives' tales about heavier being better. How often have you seen parts breaking or failing because they were not heavy enough? We cannot afford to waste raw material just because we are not sure of our design capabilities.

The Railways are often held up as an example of good design. Yes, locomotives need to be heavy as otherwise their wheels will slip at full power. Unknown to most of us, diesel and electric locomotives are actually weighted down with tonnes and tonnes of cast-iron nuggets, called ballast. But are we designing locomotives here? Do not design a dinosaur, or it will eat you alive in the end!

Next Month: Saving on Raw-Material Costs

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Harshwardhan Gupta's Design Tips–4

Saving on Raw-Material Costs

What ever happened to good old simple mild steel, cast iron, and aluminium? I have seen designers put in every sort of fancy alloys into their designs when they are not called for. And some go to the other extreme, and use the cheapest, crack-prone sheet metal, off-grade En-9 masquerading as M.S. and pig iron.

1. In most applications, one really chooses sections, say the shaft diameter, not by strength but by rigidity considerations. Often it is not appreciated that rigidity is a function of the material's modulus of elasticity, not its ultimate strength. What is also forgotten is that ALL steels have virtually the same modulus in ALL states of heat treatment. In other words, a mild steel shaft will not deflect any more than a fancy through-hardened shaft under similar circumstances. If the shafts or other parts are lightly loaded, even toughening is useless, and contributes only to the builder's or user's mental peace.
2. If a mildly loaded shaft is running on rolling bearings and no rolling (like needle bearings) or rubbing elements (like bush bearings) come in direct contact, there is no need to use anything other than M.S. Specifying unhardened En-24 gives good machinability and high ultimate strength. In other words, a shaft running under light load of ball bearings does not have to be hardened or toughened.
3. Very often, enormous costs can be saved by sensibly substituting unavailable and expensive materials in an imported design by commonly available materials. In 95% cases, it does not make any difference in the performance or life. Substituting plain aluminium plates for alloy aluminium plates is an exception, and all threads in the part must be designed out. Indian aluminium, unfortunately, does not take to tapped threads very well.
4. Static or lightly loaded springs need not be made from expensive En-47. En-42 or plain carbon steel works quite well.
5. Lightly loaded gears can be made from mild steel. No need to go in for case-hardened 4340 or En-36. Aluminium is a bad choice for gears, though.
6. Often designers specify (say) St-35 for ordinary parts, which just means steel of 35 Kg/mm^2 tensile strength, which is exactly same as mild steel. The price immediately goes up the moment the trader sees a number in the material specs.
7. Keys need never be made from alloy steels. They are meant to fail when overloaded. An extra-strong key will damage the shaft before it fails.
8. Most packaging machines, piece handling and many other machinery systems are very lightly loaded, and most (but not all) parts run with quite low stresses. Here, a lot can be made from simple mild steel and aluminium.
9. Many a times, if the volumes are low, castings and forgings can be replaced by stock materials. Redesign the parts accordingly.
10. Sprockets, if lightly loaded, can be made from mild steel too, and give a very long life if the sprockets are well aligned and the chain is lubricated with thin oil.
11. Substituting chains with timing belts makes the design much lighter and much less noisy.
12. Unfortunately, large tracts of the markets do not understand the rather cumbersome IS specifications. Asking for an exotic sounding nomenclature, or a DIN, or a GOST or a JIS material artificially pushes the price up. Do your homework, find out commonly available equivalents, again use your commonsense, and then specify materials in an imported design.
13. ISO 900x has made it more cumbersome to substitute materials. Do find a way and evolve a procedure for sensible substitution.

14. Excessive insistence of rigidity is often of no use. To design a rigid machine cover in, say, cast-iron may not serve any great purpose. Well-designed sheet metal can often be as good.

15. PTFE (Teflon) can often be replaced by ultra-high molecular weight (UHMW) HDPE, a far cheaper and superior material. Nylon / Delrin can often be substituted with this material too. Contrary to commonsense, recycled UHMW-HDPE has better properties all round than virgin material. It has the frictionlessness of PTFE; chemical neutrality of polyester, rigidity better than nylon; and machinability better than any other plastic, Wefapress of Germany is a good, cheap source of this material and finished parts in this material. You can find them on the net.

16. Almost all plastics, even if they are quite tough, have a very low modulus compared to metal. So the same part made in plastics will deflect much more than a metal part. Use this fact to your advantage.

17. Cutting intricate low-volume sheet metal blanks can actually be more economical if done by CNC laser cutting – a fairly cheap process itself. This is because the CNC program will optimize the sheet utilization and minimize the wastage to the absolutely bare minimum.

18. Redesigning machined parts into sheet-metal parts can often save money.

19. As machine-design textbooks always say, reduce weight by thinning sections and adding ribs. Everyone adds ribs but very few take the plunge to reduce section thicknesses and by corollary reducing the rib thicknesses too.

20. Making a fiberglass cladding for machine frames seems to be the fashion today, but it is better, cleaner, cheaper, simpler and actually more elegant to make the machine frame itself more aesthetic.

21. Using counter-bored holes with socket cap screws is often not necessary. Equivalent high-tensile hex bolts are much cheaper, sometimes as much by 50-60%. Plus you save on counter-boring costs. Make this change wherever it makes sense.

22. Choosing a cast material that flows more easily while pouring can reduce the ruling section of the casting and save a lot of weight, and therefore cost. In simple words, a 120 Kg casting @ Rs. 30 per Kg is cheaper than a 180 Kg casting @ Rs. 25 per Kg. Just a 3 mm reduction in a 20 mm ruling section can achieve this, for example.

Please understand the physics, metallurgy AND commonsense behind the use of materials, and keep the material specifications simple.

But keeping things simple is the most complicated thing, and the most terrorizing, isn't it?

Next Month: Rolling Bearings

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Harshwardhan Gupta's Design Tips–5

Rolling Bearings

A rolling bearing is not just a roller bearing. Let's first define a rolling bearing: A bearing that has rolling elements like balls, parallel rollers, tapered rollers, spherical rollers, needles, etc. is a rolling bearing. In the Twentieth Century, rolling bearings have become extremely common in every corner of World. And they are getting cheaper every day.

What types?

Rolling bearings come in an enormous variety. First, there are the standard types covered by the DIN numbering system common across all manufacturers: This covers standard ball bearings, self-aligning ball bearings, angular contact ball bearings, thrust ball bearings, four-point bearings, plain roller bearings, tapered roller bearings, spherical roller bearings, thrust roller bearings, spherical roller thrust bearings, needle roller bearings, etc. Besides these, there are standard bearing units with seals and housings, popularly but mistakenly called Plummer blocks. Then there are thousands of types of specialized bearings, and a whole branded array of linear rolling bearings, some ordinary – with a limited linear travel, other recirculating, with unlimited travel. So study and research well before deciding.

Advantages:

1. Easy availability, easy replacement, low cost.
2. Very low friction even under heavy loads, so savings on energy and wear.
3. High rigidity under varying loads.
4. No continuous need of lubrication (see below).
5. No wear on the shaft as there is an inner race in most cases.

Limitations:

1. Prone to corrosion if not sealed properly. (Even those made from stainless steel are prone to corrosion if chloride ions are present.)
2. Do not absorb vibrations and do not tolerate contamination.

Design Do's and Don'ts:

1. Choose the bearing properly. Most often, the bearing is already oversized from load and life considerations. For example, a 100Kg load at 1400 rpm may only need a 17mm bore 6203 bearing, but your shaft is, say, 35mm, so the bearing has to be oversized. This is okay. However you can save money by specifying a lighter bearing – say 6007 in place of a 6207 for that 35mm shaft. The bearing is already oversized, don't oversize it further.
2. Choose a sealed bearing - a 6007-2RS in place of a plain 6007. A shielded bearing like 6007-2Z is okay for clean indoor environments, not for dirty and outdoor use.
3. Bearing seals will not seal-in or seal-out even a small amount of pressure. Nor will oil seals! So positively prevent water or other stuff from seep into bearings under even a slight pressure.
4. Repeat after me: Each shaft needs TWO bearings, not one, and not three, and certainly not one rolling and one sliding bearing. Doing so is sure to invite disaster. If the shaft has an eccentric, and that eccentric also has bearings on it, then the shaft is the primary element, definitely needing two bearings, and the eccentric is the secondary element, needing either one or two bearings, depending on the detailed design. Sometimes, for a short axle, one double-row ball bearing, or one double-row angular contact bearing can be used as a virtual bearing pair, but one self-aligning ball bearing (which does have 2 rows of balls) or one single-row ball bearing simply cannot be used by itself.
5. All axial-loading bearings, like tapered roller bearings, ball/roller thrust bearings or single-row angular contact bearings must be used in pairs and at least lightly loaded against each other. They may be of different sizes. With some experience and expert advise, you can

mix two kinds of axial-loading bearings on the same shaft. Putting a ball bearing and a tapered roller bearing is inviting destruction.

6. Wherever possible (usually everywhere) use a sealed rolling bearing and avoid open sliding bearings. Nowadays, except in mass-produces consumer white-goods, rolling bearings are actually cheaper than bronze bearings.
7. Keep the two bearings on a shaft well aligned. If this is not possible, say, in a fabricated assembly, then use self-aligning bearings on both ends.
8. Never ever “match” a bearing to the shaft or to the housing. Look up the bearing catalogue, specify recommended tolerances and fits, and make the parts as per the tolerances without giving the bearing in the hands of the turner. This habit too is a pathetic hangover from the 18th Century!
9. Do not constrain the bearing pair completely. Look up any good manufacturers catalogue and properly understand what is meant by locating-floating arrangement, and apply it. This is a very common cause of bearing failure.
10. If you are pre-loading the bearing intentionally, work out where and how the reaction forces will “flow”. Else you will align everything perfectly, then distort the mounting arrangement by preloading, and end up ruining the bearings by inadvertent misalignment.
11. Never run bearing elements on hard-chrome plated surfaces, though ground hard-chromed surface looks perfect for running a needle bearing or a recirculating linear bearing on. It will flake off and ruin everything in a short time.

Duplicate! Duplicate!

Two kinds of “duplicates” are prevalent in the rolling bearing industry: the first spurious type is a new bearing with a counterfeit OEM marking; The second type is a genuine but used bearing, re-conditioned to look like new. You will be surprised to know the extent of this racket. And in many cases, if you call in experts from the original bearing manufacturers, you will find that your “regular” supplier has been taking you for a ride for years, especially if you are in the habit of bargaining excessively.

The first kind is usually (but NOT always) recognizable by poor quality markings, poor quality packs, smudgy packing dates, etc. As they say, counterfeiters are always a step ahead of the genuine guys. The only redeeming fact here is that only the popular (automobile use, agricultural pump use, etc.) bearing sizes are duplicated. Nobody will duplicate an unusual bearing that sells just a few units a year in the whole country.

The second type is easier to recognize: axial scratches in the inner race, buffed-to-mirror-finish outer races, foul-smelling oil, slightly blackened rolling surfaces, etc.

Another class is the “genuine” but cheap stuff from all sorts of mediocre manufacturers. If you use these, you get what you pay for, then pay for what you have got.

Lubrication:

Contrary to popular belief and common sense, rolling bearings require only a very thin oil film for their basic rolling function. Some lubricant in a SEALED housing is required so that the oily-greasy surfaces do not come in direct contact of moist air and other contaminants, and a tiny amount of lubrication is necessary for the cage (or retainer) lightly sliding on the rolling elements or the races. So a little bit of good quality oil or grease in a well-sealed bearing can and does last for the bearing’s lifetime. Sealed and lubricated-for-life bearings are really so. The habit of putting oil and grease in every moving joint regularly is a hangover from the 18th Century days of the open bronze bushes oozing black filth.

New (unsealed type) bearings DO NOT come coated with lubricants. What looks like a lubricant is rust-preventive oil, which has no lubricating properties! Wipe it off and lubricate the bearing, then mount it and seal it.

Many machine tool spindle bearings run in continuous oil supply. These bearings are usually heavily pre-loaded for exceptional rigidity, and therefore heat up quite a bit when running. This is normal. Here the continuous oil flow is mainly to cool the bearing, not to lubricate it, really.

Mounting and dismounting:

Never use a hammer directly on a bearing. Use a mallet (popularly called nylon hammer). Do not use aluminium bars to transmit the hammer blow indirectly. The smallest of aluminium particles in the bearings will ruin it sooner than you believe possible – typical case of a tiny ant bringing down an elephant. If possible, press the bearing in place. If hammering is unavoidable, then tap the inner race to fit the inner race, and tap the outer race to fit the outer race, never vice versa – that transmits shocks through the rolling elements and damages the bearings. To take bearings out, use good tools. Most "commercial" bearing pullers are pathetic, difficult to use and often damage the bearings. Take care dirt and chips don't go inside the bearings. DO NOT use kerosene, petrol or diesel to wash the bearings. Use mineral turpentine, and immediately saturate the bearing with its designated lubricant after a wash. Needless to say, keep everything really, really clean.

How to know if a rolling bearing has failed:

Meri Aawaaz Suno!! Listen to the bearing! The best way to listen to a bearing is to use an about 10mm diameter rod, half a metre long. Hold the rod in your hand in such a way that one end of the rod touches the middle segment of your index finger. Then put the tip of that index finger in your ear, then touch the other end of the rod to the bearing housing, or to a stationary place near the bearing. Obviously, do NOT touch the rod to running parts. This is an engineer's stethoscope. You will now hear the bearing running. If the bearing is in good condition, the noise will be a smooth hissing sound. If the bearing is mounted too loose, you will hear a loud rattling sound. If the bearing is "gone", you will hear all sorts of unpleasant noises, much like a road-roller going over loose stones. If it is screeching, rumbling, squeaking, growling, then it's time to change it. If a *brand-new* bearing is also sounding unpleasant, as if it has got small stones inside it, then the bearing is too tight on the shaft or in the housing, or excessively pre-loaded, or over-constrained, and will fail very quickly.

Rolling bearings fail prematurely due to many reasons, and we will cover that next month.

So, seal them well! Make sure the rolling elements never see the light of the day when they are running! Keep the bearings rolling, so you don't slide into a recession!

Next Month: Bearing Failure

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Harshwardhan Gupta's Design Tips–6

Rolling Bearing Failure

In India, we often let a damaged rolling bearing run till the whole machine or equipment comes to a standstill. This mentality actually does more damage to your own pocket than you realize!

Usually there are Evidences much before the catastrophe. They are: Uneven running; Vibration; Reduced working accuracy – as in machine tools; Unhealthy running noise – high-pitched whine or low-pitched rumbling; Gradually increasing bearing noise or machine noise. Increased bearing heating,

There are mechanics and fitters, who will just wash the bearing in kerosene, completely pack it with grease, and manage to reduce the noise. They have simply masked the Evidences, just as paracetamol reduces fever, but does not cure its cause.

Bearings, just like hearts, normally fail under life-long fatigue. However, abnormal conditions like wrong mounting, wrong mating part tolerances, wrong lubrication, wrong sealing, wrong alignments, all contribute to premature failures.

When a rolling bearing shows signs of distress, or fails completely, dismantle it carefully, as if it is a piece of evidence, which it is. Take care that it does not get contaminated by outside dirt. DO NOT wash, clean or wipe the bearing. Bring it onto a clean surface under bright light, scoop out as much lubricant as possible and keep it separately for study. Now wash the bearing thoroughly but with a light hand, study it and make notes, then break open the cage and separate all the elements, clean again, and investigate it as follows:

Evidences, causes and remedies:

1. Evidence: **Localized flaking (relatively deep pitting), with undamaged areas of the raceway appearing quite normal**. Classical fatigue can be recognized by pitting in the raceway of a deep groove ball bearing inner ring. The bright, slightly shining track is an indication of an otherwise normal bearing. Subsequent damage propagation results in material flaking occurring over the entire raceway. Cause: Normal compression fatigue damage, with cracks starting at the surfaces of the components in rolling contact either due to overload or damage due to foreign particles, in case of substandard bearings, inclusions in the bearing steel. In cases of advanced damage, the evidence may no longer be recognizable. Remedy: Replace the bearing, or this will lead to ruin. This is where reputed bearings score over substandard ones. Microscopic sand or slag inclusions in cheap steels leads to early fatigue failure. Misalignment and overloads, often due to rigidly constrained thermal expansions, also lead to early fatigue failure.
2. Evidence: **Blackening of the entire bearing**. Cause: overheating. Can be due to several reasons: Insufficient clearance under operating conditions, over-pre-loading, over-lubrication (too much churning at high speeds), under-lubrication, heat from external sources. Remedy: Check for tight running (bearing making gravelly noises), and reduce preload and reduce the grease.
3. Evidence: **Indentations corresponding to the rolling element pitch** in the raceways of non-separable bearings. Cause: Mounting forces were applied through the rolling elements. Remedy: Mount the tight fitted ring first. In the case of tight fits for both rings mount them simultaneously with the aid of a suitable disc.
4. Evidence: **Score marks corresponding to rolling element pitch** parallel to the axis in raceways of separable bearings. Cause: The ring was forced cross into the rolling element set. Remedy: Prevent misalignment during mounting of separable bearings. Assemble parts at the same time turning them relative to each other. Use a mounting sleeve, if necessary.

5. Evidence: **Random indentations**: Shallow indentations with very low raised edges (caused by soft particles like mild steel chips); Deep indentations with higher raised edges (caused by hard particles like carbide chips; Many small indentations with high raised edges (caused by brittle particles). Cause: Dirty mounting conditions, penetration of contaminants (defective sealing), contaminated lubricant. Remedy: Obviously, cleanliness during mounting and maintenance of the rolling bearings, use of proper seals, replacement of defective seals, periodic replacement of lubricant with washing-out of the bearings.
6. Evidence: **Brownish discoloration of the complete bearing surface**, consequential wear and premature fatigue, originating from the rust pits. Cause: unsuitable storage in more than 60% humidity; moisture condensation in storage; seal failure leading to dirt and water getting in; unsuitable lubricant. Remedy: Sensible storage conditions to comply with the specifications of the rolling bearing manufacturer, better sealing, lubricant with corrosion inhibitors.
7. Evidence: **Black etched pits**. Cause: corrosion due to ingress of acid fumes, chlorine, etc. Unsuitable storage (aggressive chemicals stored in the same room), Seal failure, Unsuitable lubricant. Remedy is obvious. Remember, most seals cannot withstand any pressure difference across them.
8. Evidence: **Marks like brinelling at roller pitch, but with no raised edges.** Cause: stationary vibrations often due to long truck rides (minute movements) of stationary machines, causing wear. Remedy: Isolate the bearings from such vibrations. Unloading the pre-load during long transportation also helps.
9. Evidence: **Corrosion in the bore of the inner race or on outer surface of outer race**. Cause: Fretting corrosion due to a loose fit, Remedy is obvious. You will have to rebuild or make the shaft / housing again.
10. Evidence: **Craters, or many craters in a row.** Cause: passage of electric current either due to bad earthing, careless welding or faulty design. Remedy: Avoid electrical current, even a low current flowing through the rolling elements.
11. Evidence: **Regularly spaced brownish fluting (fine knurling-like marks).** Cause: continuous passage of electric current. Remedy: Same as above. Avoid electrical current, even a low current flowing through the rolling elements.
12. Evidence: **Damaged cage (retainer)**. Cause: Misalignment, excessive vibrations or impacts in addition to the normal cage loads, e.g. in vibration machinery or vehicles. Remedy: Align bearings properly, or use self-aligning bearings. Use bearings with solid cages (metal or polyamide) instead of sheet metal cages. Remember, excessive vibration may lead to cage rivet fracture.
13. Evidence: **Roughening of the contact areas between rolling elements and raceways**, metal abrasion, increased bearing clearance or reduced preload. Cause: wear promoted by foreign particles and abrasion, inadequate, aged or contaminated lubricant. Remedy: Higher viscosity lubricants, EP additives, shorter re-lubricating intervals, improved sealing.
14. Evidence: **Localized welding of the components in rolling contact,** (unfortunately quite common in India) (metal particles are torn away and applied to the opposite surface), overload and seizure. Bearings with a high proportion of sliding contact friction (tapered roller bearings, spherical roller thrust bearings) are particularly susceptible. Cause: lubricant starvation under high load and speed; excessive pre-load, detrimental preload due to heat expansion, skewing of rollers due to raceway wear. Remedy: Improvement of the lubrication (lubricant, EP additives, lubricant quantity) Reduction of the preload or increase of the axial clearance. Design Change.
15. Evidence: **Roughening of raceways and rolling elements**. Very common too. Cause: Rolling element sliding on the raceway under very low bearing loads with insufficient

lubrication. Remedy: Slight preloading of the bearings, e.g. with springs.

In short, these are the culprits:

1. Open bearings,
2. Dust, dirt, humidity, aggressive chemicals,
3. Wrong mounting methods or tools,
4. Moisture ingress,
5. Too tight fit,
6. Too loose fit,
7. Too high preload,
8. Too low preload,
9. Tilted (misaligned) mounting, often in fabricated equipment,
10. Overload,
11. Too little load on a big high-speed bearing, so it bounces around
12. External vibrations.
13. External heat,
14. Excessive speeds,
15. Passage of electric current,
16. Improper (often cheap or recycled or fake) lubricant,
17. Dry bearing,
18. Over-greasing,
19. And last but not the least, counterfeit or recycled or sub-standard bearings made from cheap steel, leading to early fatigue-failure.

Chalti Ka Naam Gaadi? Think again. Damaged bearings means damaged pockets.

Next Month: Pneumatic Systems

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NEUBAUPLAN
MACHINE DESIGN STUDIO

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Harshwardhan Gupta's Design Tips–7

Pneumatic Systems

Compressed air is a VERY expensive commodity. If improperly designed and built, a pneumatic system can prove to be the most expensive thing to run. Two things contribute to this most invisible of all wastes: Leakages, and improper practices. Lets tackle both.

Hisses and silent leaks: Many factory owners do not know that a faint hiss or even a cool-feeling "just-little-bit-only" air leak from a compressed-air system is quietly costing them hundreds of rupees a day. In a big factory, this can go into thousands of rupees a day. An air leak does not drip, so no one notices it.

So, if you want to save money, first stop those leaks! Really, really stop each one of them.

1. To do that, listen for leaks when it is absolutely quiet around, after the factory has shut down or when the power goes off (have the line pressure on, obviously). Then, go around the whole pneumatic system, feeling for leaks with your hands and fingers. Spots of oil (in lubricated-air systems) around a joint usually mean a faint leak. Detection by hand is easy but exact pinpointing may be tricky, as leaking air behaves in strange ways around fittings and around piping. A solution of bathing soap (not detergents – they corrode zinc-plated parts very fast) and glycerin can help pinpoint the leak. Be careful not to let this solution seep into the electricals, or the treatment will prove worse than the disease.

2. Fix the leaks in a professional, scientific way, not like a roadside mechanic. If the sealing ring is damaged, replace it instead of using Teflon tape. Teflon tape in pneumatic fittings is generally a bad idea; as not only it suppresses leak noise, but often tiny shreds of the tape find their way into valves, pilot circuits, etc. and cause days and weeks of investigative downtime. The sealing rings, or sealant-covered threads, which come with fittings, do their job well. If both are absent, use anaerobic thread sealants of a good make.

3. Replace / repair / rebuild leaking valves, cylinders and other hardware as soon as possible. A fitting or a leaking length of tube will waste air worth its cost within ONE DAY!

Faulty Practices: Air wastage due to bad assembly is something no machine-builder wants to admit. Poor user suffers in silence since he does not know what to complain about. So lets have a proverbial 20-point programme:

1. Lower the compressor switch-off pressure: 10 bars seem to be the norm for a 6 bar final pressure. This is wasteful. You are first compressing the air excessively, and then letting it expand in the pressure regulator. To achieve what? Set the compressor on 7 bars on and 8 to 8.5 bars off and you will save 10% energy straightaway. Regularly drain the air tank of the compressor. A 100-liter tank used continuously can fill up completely with water in 1 week in rainy season.

2. Filter the incoming air well, and keep draining the accumulated condensate. Oxidized oil-mist carried from the compressor + condensate make a very corrosive, abrasive and sticky mixture. This cannot be filtered by the usual 40μ filters. Go by ISO-8573-1 recommendations.

3. Mount the FRL unit in FRONT of the machine where it can always be seen, and serviced regularly. Out of sight is out of mind.

4. If you have long air lines in the factory, have enough and proper water traps all along, and keep draining them.

5. Use 1-to-2 pressure boosters if you need high-pressure air for a few cylinders, instead of overloading the compressor and the whole system.

6. Use pressure switches to switch off the machines when air pressure drops. Low

pressure can cause freak accidents more easily than you think.

7. Always use filtering silencers in the exhausts to prevent lube oil mist making the breathing air toxic.

8. Do not attempt to clean filters. Replace them after the pressure drop across them becomes more than 1 bar.

9. Lubricated or dry air? The latter is getting more popular now. If you use a lubricator, 2 to 8 drops per 1000 liters of free air is sufficient. If your system uses, say, 100 LPM of air, then you need one drop every 3 *minutes*! I have seen people set the lubricator at 10 to 100 times that rate. This excess leads to oil accumulation in cylinder ends and valve chambers, and leads to inexplicable failures, besides making everything dirty with sticky oxidized oil spewing everywhere. If you use dry air, make sure the dryer is always in good shape. You should NOT lubricate dry air. Nor should you use “wet” air without lubrication. I personally prefer dry air systems.

10. Normal Bourdon-type pressure gauges are notoriously inaccurate and damage-prone. So if you suspect that your system is running on too low or too high pressure and the gauge is showing right pressure, then try replacing the gauge first.

11. Air tanks should be put AFTER the FRL, not before. And put a non-return and shut-off + exhausting valve between the tank and the FRL. If you try and exhaust a system through the regulator itself, you will end up rupturing its diaphragm.

12. Use smallest bore cylinders for a given job. Use smallest bore pipes to feed them adequately. For example, If a 40mm dia cylinder can do the job and 3mm pipes can run it fast enough, don’t use a 63mm dia cylinder fed with 8mm pipes with two fat flow-control valves trying to choke the exhaust to slow the runaway cylinder down. You are just wasting capital cost AND running cost. However, feed the *valves* with fat pipes (and put thin pipes between the valve and the cylinder, as I said), so you don’t starve the cylinder of air.

13. If a cylinder is only doing a momentary job – like printing a batch-code, or punching a small hole, reverse the cylinder as soon as it has reached its forward position. If you dwell in the forward position, you will end up fully pressurizing the cylinder before exhausting it just milliseconds later. That way you consume more air. Please understand that in a majority of cases, a pneumatic cylinder achieves full pressure *a little while after* it has reached the end.

14. To economize on air, don’t use a double-acting cylinder if a single acting equivalent can do the job.

15. Do not use cylinders as guides, except when the sideways loads are nil or virtually nil. Even a moderate side load will wear the cylinder end out in a few months.

16. Venturi-based vacuum-generators guzzle air at a phenomenal rate. Weigh the pros and cons before choosing between them and a vacuum pump.

17. Achieve appropriate cylinder velocity and noise by a judicious use of end-cushion adjustment, flow-control valves and shock absorbers. For the best and fastest performance, you will need all three devices.

18. Do not let pistons batter into the cylinder ends. If you hear even a moderate hitting noise, fix it, else you will have a catastrophic failure soon, when you least expect it.

19. In pneumatic systems, as in life, one who buys expensive stuff gripes only once; one who buys cheap stuff weeps *baar-baar*.

20. Last but not the least; DO NOT fool around with compressed air jets closely playing on any part of the human body. High-pressure air can very easily diffuse into the blood stream and can take a life, yes, it can kill even before someone has a chance to dial for the ambulance.

Leaking and wasted air means leaking and wasted profits. Save air and hence save money.

Kya zamana aa gaya hai, aajkal hawa bhi muft nahin hai!

Next Month: Saving on Energy

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Harshwardhan Gupta's Design Tips–8

Saving on Energy

Energy-saving is like sex in India – everybody wants to do it, but each has his own peculiar ideas, and in the process, lot of energy gets wasted. Why you are laughing? You are just not taking seriously anything I am telling!

But, seriously, how many of us realize that if we keep on going like the way we do, our own grandchildren will have ZERO conventional energy sources – thermal power and automobile fuel – left in the whole World? So where do we start?

Saving begins at home. The biggest culprit is not the staircase light, but the water heater. In most houses, unknown to the average householder, the water heater accounts for more than half of the power bill. Do invest in a solar heater. If the flame from the gas burner is reaching the rim of the utensil on fire, you are definitely wasting LPG.

And in the office? Quite obvious: Change the old incandescent lamps to fluorescent ones. Switch off all lights and appliances when not required, blah blah... But why are the lights and the fans required in the first place? What is not obvious is the need to clean up those grimy glass windowpanes and open the curtains; thus making maximum use of natural light. Yes, I know it is very difficult to clean the glass-panes from outside, but do get it done. Keep the UPS battery in good shape – else it will constantly consume power and keep boiling. The filters of air-conditioners often get choked very soon in dusty India, and make them even more energy-inefficient. They need to be cleaned every week, not every year.

The concept of a lights-always-on office comes from the West – which are actually not western but northern countries. In these countries, it is cloudy almost all year round. In winter there is insufficient light even to drive on the roads, and daylight hours are very short – in Sweden in December, you drive to office at dawn, and come back at dusk after 8 hours. And we naively follow their office design even when we in India are blessed with so much natural daylight all year long.

Do tell your architect to design your next office as a low energy building. If he does not know how to, go to someone who knows how and ask him to show you his past such work. Ceiling-level ventilators – an old-fashioned idea now – can take out the hot inside air by slow natural convection and reduce the need for air-conditioning and fans.

On the road? The usual: Pool the cars, use public transport, switch of the engine at signals… Again, there are many lesser-known methods: Drive in the highest gear possible – if the car will move smoothly, say, in third gear, don't run in second gear in a given situation. Learn to make minimum use of braking by any method, whether by brakes or by gear shifting – in other words, learn to drive defensively and gently. Don't race the engine after starting (like many drivers of old Fiats habitually do). Don't race the engine ever, actually. The modern MPFI engines don't need to be raced. Get those trucks and LCVs you are responsible for repaired and running efficiently, educate their drivers and give them fuel-saving incentives. For that matter, do that with your chauffeur too.

And at the factory? Compressors are often the biggest culprits, and stopping all air leaks (see last month's Design Tips) will bring your energy bill down. Very old motors are largely very inefficient and changing (plus downsizing) them with new motors will usually pay off within a year. Use burners that are more efficient. Black smoke always means incomplete combustion. In plain words, that black cloud coming out of your factory is your own money drifting away in the air.

If it is a machine tool, use a well-sharpened, smoother-cutting tool, and you will immediately save power. Power saving in a machine-shop is usually completely ignored, but a few weeks of investigation with an energy meter connected in series with the incoming line to monitor individual machine tools will immediately throw up the culprits. I know this is unheard of, but if you want to save on your power bill, invest in a portable power meter, or hire it for a few weeks. Check what operations consume what power and what action reduces that figure.

Get a proper Energy Audit done from qualified people. Know that all wasted energy appears as heat somewhere or the other, and a lot of electrical and mechanical energy makes very little heat. If you are a big consumer of energy, ask them to use infrared cameras to locate "hot-spots" of energy leakages as heat. Leaking compressed air will show up as cold spots, not hot. The Energy Audit is not a bureaucratic exercise, or just hot air! Do take it seriously and do a merciless job, without office politics. Remember that you are actually benefiting your own grandchildren!

How can the design office contribute? Charity begins at home, they say; and energy saving begins at the design office. Why blame the state government for the power crisis, when the demand is going up partly because of inefficient and wasteful use. So, what do I have to say to my fellow machine designers? Plenty!

Are you quite sure that machine needs a 3 HP motor? I can safely bet with you that it will peacefully run with a ½ HP motor. I know I will win 80% of the time. Yes, I know that a motor consumes power proportional to the load, but there is something called part-load efficiency and fan losses; and at every start and stop – energy loss due to higher inertia of the heavier motor plus drive. So, use a smaller motor, and save money in the drives too. If you are using a heavier motor just because it is starting a large inertial load, then use a soft-start and a smaller motor instead.

I was once called in to solve a problem of large motors of a hammer mill getting burnt out. The mill originally had a 25HP motor, which burned out, so a 35HP motor was put in its place. That burned out too. Then a 50HP one died, and then an incredible 75HP was about to meet the same fate, when I was called in. The motor was running as hot as a ready *chapatti ka tava*. The cause was not overloading at all! The outlet of the cooling fan (the place where the air blows out from the fan cowling to flow through the cooling fins) would get progressively choked with the sticky dust flying all over from the hammer mill. The necessary cooling action would progressively reduce, and finally stop altogether – so the burnouts. What is the moral of this story?

Do avoid high reduction-ratio worm gear drives if they are constantly running under heavy load. You are constantly losing energy in their gross inefficiency. Replace them with multi-stage helical reducers. If the reduction-ratio is in single digits, use a series of timing belts instead of worm or helical boxes. Avoid sliding bearings, and keep rolling bearings in good shape. Avoid friction, basically.

Take a h-a-r-d look at the air cylinders you have used in your design. Make their bores and strokes as small as you can (see last month's Design Tips). Stop all leaks. Keep air tubing from the valves to the cylinders as short as you can – tubing length before the valve does not matter. Don't oversize hydraulics either, and use proper unloading valves. Design the hydraulic system in such a way that it uses minimum energy. Servomotors can often replace hydraulics and consume much less energy.

Saving material and weight also indirectly saves energy, as raw materials need much energy to be produced. No gram or watt or joule is too small to ignore. Save every bit of energy and material – that's the mark of a good designer!

Time travel is definitely possible. We just have to keep on wasting energy – and by 2050 A.D., we would be back in 2050 B.C.

Next Month: Tolerances

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Harshwardhan Gupta's Design Tips–9

Tolerances and Fits

"Everything is in absolutely zero-zero! We did matching with your bearing only! Not going? Krishna, take it and put little polish paper on that Rajkot it is empty, tell Kaka don't do minus! If it goes minus, we will have to unnecessary send for haadcroam 3 days it will take. So what I was saying? Yes yes, we of course fully inspect 110%. You don't worry! Whatever plus minus tolerance you are giving, we are maintaining 110%. Little bit out and we are straightaway doing rejeksun. I myself full Diploma engineer, Sir. Our Quality Control is very very shtrick. Sorry, Assurance, Assurance, Quality Assurance, not Control. Quality Control is now old fashion no, hee hee. Nowadays Assurance is there in place of Control. And we are always doing best relation maintain with your purchase, inspection, everybody. But I tell you; nowadays even bearings are coming minus bore. All &^$%@ duplicate business going on. Yesterday only I triple checked original pack SKF 50 bore with dial myself only. It was showing half thou minus!" (Which is exactly what the SKF catalog specifies, by the way.)

Familiar scenario, isn't it?

At times I wonder that, for all our rapid industrialization, are we really a manufacturing nation? Or are we essentially a nation of traders, having somehow done a diploma course, who are employing agricultural labor to work on contraptions made by next town's blacksmith, and doing industrial manufacturing business by underhand deals, rather than on quality?

And what is this tolerance business?

In the 18th century, gun-making companies in Europe, employing hundreds of gunsmiths, invented the concept of interchangeability to enable soldiers to interchange their guns' parts in the battlefield. This concept of interchangeability of parts worked so well and proved so economical that its use spread like wildfire to all gun-making factories, then to other industries, and then became the driving engine of what we today call the Industrial Revolution. The Industrial Revolution simply could not have come about without the then unique concept of interchangeability.

In stark contrast from those times, today we simply take it for granted that when a part of some machine or gadget becomes unserviceable; a new part to replace it will fit perfectly in place of the old. Therefore, the first word in the Quality dictionary is not "assurance" but "interchangeability" – or predictability, in a more general sense.

This interchangeability is central to the whole industrial World. The lifestyle we all are used to nowadays simply cannot exist even for a day without interchangeable parts, assemblies and machines. To achieve this interchangeability, the industrial World has devised a system of 'tolerances'.

Quite simply, tolerances are nothing but dimensional limits within which a part can be manufactured so that, firstly, a desired fit – tight, loose, locating, running – is achieved with the mating part (which is also made to corresponding limits), and secondly, the piece-to-piece variation in that fit remains within acceptable limits.

Most engineering handbooks contain tolerance tables and explain the method of choosing them fairly well, so I am not going to go into that part of it here. The problems lie elsewhere. I am outlining the problems – the solutions are obvious!

1. Most of the tolerances are specified on the drawings by the designers / draftsmen, who usually have absolutely no hands-on experience of either manufacturing or assembly or both. Most such guys hide behind their ignorance and try to use their handbooks as shields, throwing their "theoretical" weight around when their parts don't assemble right or work right, blaming it on the blue-collar guys. This is the commonest point of friction between the 'upstairs' and 'downstairs' guys.
2. Some design guys, wanting to err on the safe side, specify the tightest possible tolerances, making the part unnecessarily expensive.

3. Others have no idea or experience of metrology, and specify tolerances in such a way that either they are impossible to achieve, or impossible to measure.
4. Still others completely bypass the standards, and give absolute limits by 'judgment' (All this H7 and g6 and F9 business I don't understand only!) These guys will specify ±0.02 on 20ϕ, and the very same limits on 250ϕ also, aiming to get the same fit – which is nonsense.
5. Still others are very fond of specifying shrink fits and press fits. So, the poor shop floor guys, neither having heating and handling arrangements, nor a big press, resort to 10 Kg hammers and wooden blocks, ending up with material shavings on the floor. If a tight fit is required, often industrial adhesives can be put to good use. (See Design Tips #1, IPF November 2002, page 195) These press-fit buffs often forget to specify an entry chamfer, so the shop floor has a hell of a time assembling. At other times, the turner puts a small chamfer and the grinder removes it completely. Inspection guys are busy setting their bore gauges – what is there to inspect in chamfers?
6. Others make mistakes with capital and small letter denotations.
7. Still other will either convert the denotations (e.g. 30H7) to absolute values in the drawings, which is okay for production but creates havoc in a design review.
8. Others give only the denotations and expect the shop floor and inspection room to convert them to absolute values – recipe for a whodunit detective novel!

So much for the design office! Lets see what happens elsewhere.

1. Many vendors will invariably ask for the mating part and achieve a 'fit' by trial and error on the lathe or the boring machine. This is criminal! Such surfaces invariably become tapered, and play havoc with the bearings, etc.
2. Many factories work with worn-out or out-of-calibration measuring instruments.
3. Other places give worn-out instruments to the machinists, and a 'new' set to the inspectors.
4. Others use bearings to set dial bore gauges, or routinely set them on built-up micrometers.
5. Many don't have a Height-Master, so they can't check right angles properly. Others use 'commercial' grade try-squares.
6. In my observation for the last quarter-century, a good percentage of the people – machinists, inspectors, engineers – simply DO NOT know how to correctly put a Vernier caliper or a micrometer on the job. I have personally come across scores of people who will insert the Vernier caliper jaws just about 2mm inside a bore, then tilt it sideways, anywhere from 15° to 45°, then pronounce their verdict most confidently – Job is reject, Sir.

These individual shortcomings, going up the manufacturing ladder till we reach the national level, add up to an enormous wastage of man-hours, energy, money and materials, and results in inferior quality and unreliability. Our population is World's 22% and our total exports are World's 0.8%. Out of which, an extremely large chunk is non-industrial export. Out of this, machinery and hardware export to the First World is disgracefully negligible. Machinery export to the First World by Taiwan, Korea, China and other Southeast Asian countries put together may exceed our industrial GDP.

We are importing, using and discarding high-tech stuff – cell-phones, cars and their parts, home theatres, laptops, Laser mice, etc., at a furious rate, but we are not even mildly participating in their globalized development and production. With negligible exceptions, whatever high-tech stuff is being manufactured in India is under a foreign name, design and control.

Are we even a technical nation, leave alone being a technological nation? Well, throughout our long history, we have always placed software above hardware. We could write reams of Upanishads and invent the zero, but could not invent and develop electricity, or the water wheel. Today, we can write billions of lines of source code, but cannot design and manufacture a hard disk drive on our own.

We Indians have a lot of tolerance! Mahatma Gandhi said so, no? But then why don't we fit into this World's sprawling manufacturing system?

Next Month: Roller Chains

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Harshwardhan Gupta's Design Tips–10

Roller Chains

One of the sturdiest and cheapest forms of mechanical power transmission is the roller chain. The only thing cheaper than a roller chain drive is a plain flat belt. It is neither as efficient, nor positive. A V-belt drive would cost almost the same, if one designs, makes and installs it properly.

Roller chain, though the commonest, is only one type of many transmission or transport chains. Others are bush chains, conveyor drag chains, slat chains, etc…

Low costs aside, there are many pros and cons, and dos and don'ts with using roller chains. Some are common knowledge, others are not so commonly known. We will tackle them all here.

Advantages:

1. Low overall cost, as I said.
2. Easy to make and install even with primitive facilities.
3. Can tolerate a limited degree of misalignment – more than gears and timing belts but less than plain or Vee belts, both axial as well as angular – though it is not a good idea to let things go out of alignment.
4. Positive drive.
5. Can absorb a fair amount of shock loads.
6. Can go around many sprockets, on both sides of the chain path.

Disadvantages:

1. Needs a housing at high-speeds, unlike belts.
2. Noisy and fairly unsuitable at high speeds, unless completely enclosed, sealed and lubricated properly.
3. Needs adjustable CDs or jockey sprockets to tighten the inflexible chain.
4. Needs more careful alignments than V-belts.

Dos and Don'ts for designers:

1. Unless you are very sure of what you are doing, don't use a roller chain above about 500 rpm.
2. Always run chains almost without slack but not tight like belts, and not sagging like hammocks. Use either idler-tensioners or adjustable centers. Unlike timing belts, chain drives cannot be designed to assemble tightly on fixed center distances. This is important when the chains are almost vertical.
3. Do not harden sprockets if the running speeds are low. Nothing is gained by hardening for low-speed drives.
4. Always blackodize or phosphate the sprockets, especially if the chain remains idle on them for long stretches. Zinc or cadmium plating is okay in but do not nickel plate, electroless nickel, bright chrome, or hard-chrome the sprockets. If food-grade cleanliness is required, the roller chain is anyway the wrong idea! Use timing belts instead, or enclose the drive in an appropriately sealed housing.
5. Remember that standard roller chains are made and assembled on high-quality automatic machines; and non-standard chains, like conveyor drag chains, etc., are often made with cheap press-tools and manually assembled, resulting in serious pitch-errors, weak spots, heavy wear and tear, and high friction. In other words, if you can do with standard chains with extended pins or extended leaves, do not use non-standard ones. I have seen some disastrous consequences of that.
6. Using sprockets of less than 17 teeth leads to vibrations in the chain and the shafts – invitation to fatigue failures – of chains, bearings, shafts, everything. Even idlers / tensioners should have at least 17 teeth.
7. It is not at all a good idea to use plain disks, or rubber rollers, or rubber shoes as tensioners.

8. It is also not a good idea to use spring-loaded tensioners – they may lead to excessive vibrations. Loading a chain tensioner with a tension- and not compression springs is inviting catastrophic failure. If the tension spring snaps, the chain will become a weapon of mass destruction. Tensioners are best adjusted and locked.
9. Just like belts, chains also need sufficient wrap to work well.
10. For fixed center distances, calculate the theoretical CD, and then reduce about 10% of the pitch, to get a nicely fitting chain. If you keep the distance exact, the chain ends will simply not come sufficiently close to assemble the lock.
11. Try and avoid offset links – they are manufactured very infrequently, and may not match the chain well. They literally are the weakest link.
12. Use multi-strand chains in place of bigger single-strand chains. However, these are more susceptible to misalignment.
13. Many sprocket manufacturers try to cut corners literally by using undersized blanks for the sprockets. This can be recognized by the presence of an excessive land on the crest of the teeth. Ideally, there should be no land whatsoever, but a small 0.5 to 1mm land is okay as a way to chamfer the sharp teeth. Anything more should be rejected.
14. I have seen many thin, large sprockets wobble sideways on their axes. This is just poor fitment and careless manufacturing / handling.
15. Chains can take a lot of abuse, but make sure there is no catastrophic accident if they fail.
16. Always assemble chains with locks. Do not join them by riveting to make them endless.
17. Chain drives – if properly designed and maintained – last long. Often the failure points in the whole drive are the bearings and keys, even shafts failing by fatigue failure. The usual reason is that the chain is often more over-designed than its companion components.

Dos and Don'ts for assemblers and users:

1. Do not assemble chains the way you do on a bicycle. Open the lock, wrap the chain and assemble the lock again.
2. Do not, repeat DO NOT lubricate roller chains with grease or viscous oil. Use a high-penetration lubricant like Singer Oil. The reason is simple: Lubrication in a roller chain is needed between the leaves, and between the pin, bush and roller. Only a low surface-tension, low-viscosity lubricant will reach there by capillary action. Grease and viscous oils only lubricate your mind into a false sense of security.
3. If the chain is operating in a dirty environment, grease it AFTER lubricating with high-penetration lubricant. However, in an abrasive environment, grease will abrade the chain even more. In such cases, put a fully closed guard.
4. Align the sprockets carefully. Better alignment directly means substantially longer life. The importance of this must really be understood.
5. Remember, when sprockets and wear out, the chain starts riding higher and higher on the sprocket. So, if you can see a gap between the tooth root and the chain, the chain is worn out.
6. Always keep blackodized sprockets and chains well-oiled to avoid corrosion.
7. If a high-speed chain is making a whining / grinding noise, the sprocket teeth may be having an incorrect form, or there may be a slight angular misalignment.
8. If a low speed chain is making a random snapping noise, then either the sprockets are badly misaligned, or – more likely – the chain is too tight.
9. Discard a sprocket whose teeth have lost their symmetry even slightly. They are worn out! Don't wait till catastrophic failure.
10. If the slack side if the chain is continuously jumping up and down, it is too loose. If tightening does not correct it, the sprockets teeth may be eccentric with the bore.
11. May I remind all you gentlemen that the CLOSED end of the U-clip locking the chain

must face the direction of running of the chain, not the open end?

12. In the sprocket, look for defective welding between the hub and the flange. Ideally, a sprocket should be one-piece. If it is welded, it must be stress-relieved properly.
13. Do not buy or use painted sprockets. They will ruin the chain and can hide welding defects.
14. While inspecting a chain, open the lock and unwrap it, soak the chain in kerosene and wash it thoroughly twice with fresh solvent, inspect it for wear, scuffing and fine cracks. If these are present, replace the whole chain, not parts.
15. Don't let chains rust even mildly. Rust pits are the starting points of fatigue cracks.

Chains are everywhere: Chain marketing, Chain snatching, Chain mail, Chain of stores, Chain of command, Chain reaction, Daisy-chains, Key-chains, To stop train pull chain… *Chain maintain karo, aur chain kee neend sowo!*

Next Month: Fasteners, locks, split-clamps

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NEUBAUPLAN
MACHINE DESIGN STUDIO

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Harshwardhan Gupta's Design Tips–11

Fasteners, Locks, Split Clamps

A bit of classification for clarity: A fastener is (generally) something that keeps two or more parts together, which otherwise would fall apart. This therefore excludes welding, brazing, adhesives, round parts pressed into round holes, but does not exclude screws. "No giggling in the back benches! Why you have such dirty minds?" The next grouping is between threaded and non-threaded fasteners. Threaded fasteners are obviously screws, nuts, studs, bolts, helicoils, etc… There is a HUGE variety available in all qualities from superb to rubbish with any decent hardware supplier. Non-threaded fasteners are things like circlips, keys, split pins, rivets… Locks are things which lock the various fasteners against loosening, like spring washers, star washers, roller chain locks; or are devices openable by bare hand – like electrical cabinet handles or toggle latches. Split clamps are features that lock a part with a side-slit round hole onto a round bar by applying tangential clamping by a screw – worm-type hose-clamps are a variant of the split clamps.

In this article, I will not go further into classifications and definitions, but try to correct some of the bad habits and myths that surround designing / assembling / using fastening devices.

1. **Beware of duplicates and sub-standard makes of fasteners and tools!**
2. Use high-quality, *high-tensile* bolts, nuts and Allen screws, correctly called socket-head screws. With high-tensile fasteners, you do not need to use first a plain washer, then a spring washer. You can tighten high-tensile threaded fasteners sufficiently to get a virtually vibration-proof natural friction lock.
3. Go through appropriate IS / DIN / ISO standards before specifying fasteners and designing threaded / mating features. Many junior design engineers don't know that the passing hole is bigger than the screw diameter, circlip groove is wider than the circlip, there are two basic types of spring washers (one of them happens to be meant for 'Allen' screws) etc., etc…
4. Nice fat thick plain washers should be used when the bolt or screw is tightening on an adjustment slot.
5. It is criminal to make tapped holes oversize just so that tapping becomes easier. You are weakening the joint, and sooner rather than later, the ill-fitting screw will screw you in turn. "Nut screws and bolts", as the old PJ about a psycho rapist goes!
6. All threaded fasteners come loose with vibrations. Using locknuts is a poor way of preventing it. Split pins are okay but can lead to fatigue cracks. Anaerobic thread-locking adhesives are good – they can be undone by a few drops of pure toluene. Nylock nuts are good. Spieth nuts – a variant of lock nuts – are excellent. These are two ring nuts, one with tapped holes in the rim, one with through holes in the rim, kept axially apart on the shaft by a millimeter and fastened together with small screws. The axial gap between the two is a MUST! No gap – no locking! The theory correctly says that if the fastener gets completely unloaded at some point of the vibration cycle, it will definitely get loose quite quickly. Spring washers prevent just this, and that's how they work so well.
7. In a machine (like a car), It pays to re-tighten ALL fasteners after a few months of use. Even better to repeat it after another 6 months. If you do this (say) to your car, for example, you will never have body noise or door rattling.
8. Talking of fastened joints, a machine's or structure's rigidity is a sum total of the rigidity of its parts AND its joints. If you join two fat castings or two heavy fabrications by insufficient number and / or insufficient size of bolts, the overall assembly will have very poor rigidity, and you will keep wondering what happened to your rigidity calculations. This also does mean that you festoon the joint with so many big fat bolts that there is insufficient

spanner space. Many hydraulics designers are experts in doing just this!

9. In all my professional life, I have met very few designers who can properly proportion a split clamp. To give you an idea, for a 40ϕ shaft, the width of the slimmest portion of the clamp should be about 4-5mm, bolt should be M8 or M10, and the thickness should be 20-30mm. More width will stress the screw too much by the time sufficient clamping is achieved, and less width will stretch the material. Too much clearance (my ideal is H7-f6) will make the slit shut. Too little thickness will cause insufficient rigidity. More width than 30 (in this example) will need more than one screw. Anything beyond 40 is functionally useless. The slit should be 2-3mm in this case. The bolt should be as near the shaft as possible. I would only keep 2mm minimum material! Any material along the slit and beyond the bolt head is useless. If properly designed and made, a split clamp can surpass a shrink-fit in performance.
10. As far as possible, design keyways in shafts close-ended on both ends. It is not only neater, but physically the key cannot come out with vibrations. The key should be retained by a setscrew right on it. From 6x6mm onwards, it should also have a tapped hole to pull it out of the shaft. Follow other guidelines for keys in the standards. If the torque a key carries is not critical, you can safely (and not at all inappropriately) use a smaller size key than one specified in the standards. Avoid very long keys.
11. Keep appropriate space for entry and turning of spanners AND for the human hands using the spanners in the machine. This may be stressing the obvious, but I have seen some real boo-boos here.
12. Keep sufficient thread engagement. Though the standards say 1.5 times screw diameter, I recommend 2.5 to 3 times, as our fasteners are always grossly undersized, and female threads are oversized, or tapered, and the materials have a real low yield point, so threads often strip off with 1.5-times type design.
13. Keep sufficient tap drill depth, as our workmen are experts in stopping at the first or the second tap after they have bottomed it, so you are cheated out of the available tapping depth.
14. Machinists, especially lathe operators, are past-masters in merely starting the thread, and reporting the job as complete. It is left to the poor assembly fitters to complete the half-done job. If after tapping, the job has been hardened and ground, get ready to fill out the rejection report / rework note. Some Brave Hearts try to tap a half-tapped hardened job, and break the tap inside. Then the oldest fitter in the factory gets a chance to show his skills.
15. It is usually below the dignity of a machinist to tap the holes he has drilled. A job worth tens of thousands of Rupees is done on a CNC machine and then undone by the ITI apprentice by tapping it "cross" – the tap not having gone in at right angles. For some inexplicable reason, it is completely alien for a vast majority of our machine-shops to have the MACHINE run the tap after having drilled the tap hole. They think a great saving is achieved by manual tapping, and they think it is "safer"(?!?) – if a machine breaks a tap, it is the machine's fault; if a man breaks a tap, it is the material's of the tap's fault!
16. Do not tighten hex-head bolts using an adjustable spanner. That tool is for emergencies in a remote roadside. It has no place in the assembly or the maintenance shops.
17. The pipe wrench is for working with pipes, not with big nuts or other fasteners.
18. Work circlips with good imported circlip pliers, not with hand-filed bright-chrome plated pieces of utter shit that are sold in India in the name of circlip pliers. (I am ashamed to say that Chinese circlips pliers are far better than ours, and German ones are perfect)! If you are travelling abroad, please get a good set of circlip pliers for your shop.
19. When you are rummaging through that sexy German hardware store, please also get a set of ball-ended Allen drivers. These are Allen keys with a garlic-like hexagon-faceted ball at

the useful end, and a screwdriver-like handle at the other end. It can drive Allen screws even at 30°angles from normal. You do get long ball-ended keys in India (better than the common or garden variety, but nowhere as handy as these Allen drivers) but none of our resourceful importers have yet thought of importing this extremely useful tool.

20. When you can use a box spanner, don't use a ring spanner. When you can use a ring spanner, don't use an open spanner. When you can use an open spanner, don't use an adjustable spanner. When you can use an adjustable spanner, don't use a monkey wrench. When you can use a monkey wrench, don't use a pair of pliers. When you can use a pair of pliers, don't use a chisel or screwdriver, and a hammer… That's the mark of the callous and the uncaring.
21. Please don't paint fasteners. Remove jammed and rusted fasteners with good old WD-40. Many recent products are better.
22. Zinc plating with passivation is fine but the fatigue-strength is definitely reduced unless you do dehydrogenation after plating. Never ever electroplate spring washer, circlips, Belleville washers or any stuff made of spring-steel.
23. Don't add a 3-foot pipe to increase your leverage on a 200mm long hexagonal wrench (allen key). And I beg you to not to work with broken, modified or damaged tools / fasteners. I especially beseech you to not to use "duplicate" tools like spanners. You are only spitting on yourself.

Writer ka screw thoda saa loose hai shayad!

Next Month: Adjustment-free machines

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Harshwardhan Gupta's Design Tips–12

Adjustment-free Machines

Kindly adjust – the quintessential Indian way of life! Learn to adjust; we are reprimanded in our childhood. Marriage *ke baad sab* adjust *ho jaata hai* – our parents counsel us! We bring the same philosophy into engineering and design.

Everything was adjustable in old, pre-WW2 European and American machines. The reason to keep everything adjustable was to compensate for errors and deviations in manufacturing, where today's precision was impossible or prohibitively expensive to achieve. Then in India, we got our freedom and firmly shut our access to technological developments in the West. This created a bizarre situation. Throughout the 60s and 70s, people (usually enthusiastic craftsmen teamed up with equally enthusiastic entrepreneurs) merrily copied machines designed and built in Europe and USA, which at that point in time were anywhere between 20 to50 years old. Many did a creditable job of copying, yet never gave a thought to eliminating adjustments. On the contrary, they went on festooning their machines with even more adjustments. With operating manuals in India being sketchy and badly written at best, and non-existent at worst, adjusting a machine became the most well-kept secret by the workmen involved – both of the machine-builder and user – one training the other. So much so, that even their bosses, the "service" engineers and the owners never quite knew how to do these "critical" adjustments. This situation still prevails with thousands of machine-builders in material-handling, packaging, printing, pharmaceutical, food, canning, bottling, cigarette-making, jewelry making, SPM industries… virtually everywhere.

In many typical cases from these First-World industries, (Manestey, IWKA, Grafo, Heidelberg, Stannco, etc…) the original old – really old – machines had quite a few adjustments, and subsequent Indian copies went on making more and more parts and assemblies adjustable, as the makers encountered problems, and the resulting product became uglier and increasingly troublesome, and needed an accomplished artist to adjust it right, even at the operator level (But I tell you, since that Harkisan fellow adjusted it is running very fine for last 4-5 months 70-80% production we are taking out!). In the same period, these very First World companies went on to making increasingly sophisticated machines, removing most of the adjustments as precision manufacturing became more the norm, and labour became more expensive.

So where does that leave us? Why do we need adjustments? Well, some adjustments are required to set the machine up for different sized products. This is usually accompanied by a change of tools too. It is a sobering thought that many European companies (Uhlmann, Dividella, IMA, Manestey…) are now supplying 100% pre-adjusted tool-change – mechanical engineers' answer – no, forerunner – to "plug-and-play" devices! In 1990, I myself have seen cartoning machines, specially designed for very short runs of a wide variety of cartons, made by Harro Hofliger of Germany, where all adjustments were motorized with position feedback, and a menu-driven program adjusted the machine to the chosen settings, and the machine got ready to run a new product within 3-4 minutes! This is not at all difficult to achieve by any good machine-builder in India – it only needs a change of attitude, and a good designer. The machine tool industry has been doing it for many years: in the form of Automatic Tool-Changers for CNC machines!

Back to our topic – the rest of the adjustments simply exist to hide the machine-builder's / designer's shortcomings. This is what the machine builder and his designer have to put their minds to. An obvious but oft-forgotten pre-requisite is willingness to change, as I just said. Assuming that is present, where does one start? With a 1:1 scale drawing, on paper or more likely in AutoCAD nowadays! This drawing must first be audited if it has been made by measuring and drawing parts of another older machine. The drawing by itself must be really accurate, VERY detailed, to scale in every detail, (Always keep that "Ortho" and "Snap" on, my CAD-using comrade!) and must make sense by itself. It should not rely on the basis that "if it works in the actual machine, even the obviously wrong design must be taken as okay". Check for things like whether gear center-distances are theoretically correct, whether the bearings come into the right place with right axial locations / floats, whether the toggle geometry is correct, whether the cam geometry makes sense, etc…

Once this design drawing is thoroughly audited, part drawings should be reviewed next. Main thing to check for is: what dimensional variation (tolerance, that is) can the design accept, rather than with what tolerance can the part be "conveniently" manufactured. If all documentation makes sense, then patterns / castings / fabrications (Quality is little bad but he is doing very cheap you know!) and other manufactured parts should be checked if they conform to the drawings. If you are in the habit of not making parts as per drawings in this 21st century, or worse, you make parts without having drawings for them, then I am at a complete loss of words!

On the other end of the spectrum, there are those who put a tolerance on every single dimension and clutter the drawing with form tolerances. This only makes everyone's life miserable and pushes the cost up. For dimensions and features where no special tolerance is needed, but which do contribute to the overall quality, there is something called open tolerances (defined in IS-2102). This is often misunderstood as no limits at all (Tolerance *kahan diya hai, dikhao?*). Many think open tolerance simply means ±1mm universally, whether it applies to 20mm or 2000mm. Others argue that 20mm without tolerance must mean 20.000mm. Still others make everything "within tolerance" but the right-angle is off by a whole degree, without realizing the havoc that can cause. "Happens *bhai*, what to do? You have to adjust! How many times you will do reject reject reject?"

This is where precision manufacturing comes in. Are you accepting medium-sized castings that are badly warped and are dimensionally off by many millimeters? Are you matching shafts to bearings? Are you machining off a cheap part to save an off-size expensive part? This is where you need to stand up and reject dimensionally unacceptable parts. Please also remember that good finish and good tolerances are two different things.

In well-made components, very often the passing (clearance) holes for fasteners, when made as per IS-1821 / ISO R/273, provide sufficient adjustment opportunity to compensate for acceptable manufacturing errors. In simple language, 7mm hole for M6, 22mm hole for M20, etc. You don't have to make the holes any bigger or make them oval, then cover them with big ugly washers.

If you have to provide valid adjustments, don't keep a (say) 50mm range – just to be on "safe side" – when geometry + calculation says only 22mm is required. This can actually make your design more compact.

Where locations must be frozen in place after careful alignments, as in machine-tools, dowel pins are the obvious answer. Threaded and hardened tapered dowels are the best.

Now, assuming that you have a proper design and are assured of properly made parts, *have a good look at each adjustment provided in the design and review it. Is it REALLY necessary?* Be ruthless, and be sure of your geometry and your fundas. What will happen if that adjustment is removed and the part made to fit in one given place? Something else may go out of synch? And is that adjustable too? So, remove both adjustments! Now the keyway must be in a given orientation compared to the PCD holes? Then say so in the drawing, it's not such a big deal! Check again – are you afraid of removing those uncalled-for adjustments because… The boss will not approve? Something "unknown" might go wrong? You believe your customers like them? You are too lazy? You think that might increase the cost? You think it might need going to more expensive vendors? You are too busy with other problems? You don't want to experiment? A known devil is better than an unknown devil? You are not sure how to do it… Well, there are very sound economical and management reasons to design-out adjustments:

1. Increased component cost usually gets offset in reduced assembly and try-out time, which is when all the investment has already been made and the machine on the assembly floor

is just that much money sitting idle for long weeks producing no financial returns!

2. Removing adjustments simplifies the design, reduces number of parts and thus reduces cost too. The design effort goes in only once, adjustments cost you extra in each single machine.
3. Erection and commissioning is much easier after delivery, thus shortening installation time and expenses.
4. Assembly-fitter / user training time and cost is reduced.
5. Critical skills are not lost when an experienced fitter leaves your organization. Or when you have to retire him.
6. Heavy use and vibrations don't put the machine out of alignment, so MTBF improves.
7. Parts like gears (especially bevel gears) normally don't wear out so easily; they do if someone adjusted them wrongly, because someone else made them adjustable. Change-gears, Timing belt drives, roller-chain drives, can ALL be designed for fixed centers.
8. It makes the machine much more fool-proof, and much less person-dependent.
9. Service calls during warranty period are reduced, as there are lesser adjustments to go 'out'. This in itself is a HUGE saving. Please realize that just because you kept everything adjustable, a few unintentional screw-ups by the user can wipe out your entire margins on that particular machine just in making 2-3 avoidable service calls 1200 km away.
10. Assembly fitters / machine operators / unions can't hold you to ransom (Fully open this fellow is writing! One has to be diplomatic no?)

Remember the days when every single part in the old Premier Padmini "dikky" and door latches, locks and hinges was adjustable, and every few months there HAD to be "*thoda* ajjusment by *apna* Balbir Singh Mechanic? Very good he is, *ekdum* best but charging much too much nowadays, very busy also he is nowadays! Just 2 year old and doors are giving trouble again again, all because so many @#$%& potholes in the roads! Very bad you know, when we sit in car whole building knows, so much door banging is there Sheela Auntie from fifth floor regular asking morning evening where who was going in car!"

What you are talking all rubbish don't adjust don't adjust? How much I have to adjust everyday you don't know! Nowadays even *Saas* has to adjust to *Bahu*! Our old time it was not like that!

Next Month: Designing silent machines

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Harshwardhan Gupta's Design Tips–13

Designing Silent Machines

"Shut up and be quiet! Don't make so much noise!" Can one say that to a machine?

Yes, the designer actually can! But first, why is there a need for silence? Many reasons – some are obvious, others not so obvious. Most obvious is the sound pollution, and high noise-level is a definite health hazard. High noise adversely affects concentration and leads to annoyance and fatigue.

Not so well known is the fact that today, noise is associated with bad quality. Many engineers don't quite realize that **if a machine is producing unpleasant noise, then almost as a rule, something is being destroyed somewhere!** I have found this to be very true.

Some machines are inherently noisy: stone crushers, where the stones cracking up themselves produce noise, or a high-velocity air nozzles, hammer mills, wood-shaping machinery, glass-bottling lines, a train running on rail joints. But most others could be made quite silent. Over the years, almost every machine has become increasingly silent: cars, computer printers, even buses and trains. Modern milling machines are quite silent now, thanks to gearless spindle drives… The most noticeable noise reductions have taken place in looms and in automobile engines. This is high-tech – which is nothing but application of science and attention to detail.

So, who are the noisemakers, the culprits – so to speak? Gears, bearings which are not pre-loaded, bearings with too much or too little radial clearances, unbalanced rotating parts, pneumatic valves without silencers, loose parts…

There are two ways noise is transmitted. One through the physical machine – what is called structure-borne noise, and second, one through the air – called air-borne noise. You only feel the first (as vibrations) and you only hear the second.

Some machines like fans and blowers directly produce airborne noise, most others usually produce structure-borne noise, which at some other point in the machine becomes air-borne. Sheet-metal edges, large sheet-metal panels convert structure-borne noise to air-borne noise. Cheap commutators in DC and universal motors often produce a siren-like sound.

Many cheap pumps sold in India produce cavitation noise, (a sort-of continuous rattling noise) which is produced when entrained air bubbles – or water vapor bubbles forming at one place (due to bad rotor design / poor manufacture) and collapsing on a surface somewhere else on the impeller or the casing. This consumes more power, reduces efficiency and ruins the pump in a few years.

So, the designer should attempt to identify sources of noise and eliminate them systematically. Please do not go by gut-feeling solutions and immediate fixes. A very common source is unbalanced parts, so balancing is an obvious remedy in many cases.

Noise reduction is a vast and complex science and noise problems cannot be tackled by hit-and-miss methods. Merely putting padded covers on the machine is only covering up the problem, not eliminating it. In this article, I have merely drawn attention to some of the problem areas and broad reasons. Giving solutions to specific problems would result in a 4" thick textbook! But such books, even handbooks, are available in any decent technical book store.

Here are some tips:

1. Tighten all nuts and bolts. Make sure they remain tight.
2. Stiffen large sheet-metal panels as required. See the stiffening done on the underside of a modern car's bonnet.
3. Make door hinges free of play.
4. Pre-load high-speed bearings with suitable disk springs.
5. Excessively rigid frames only change the natural resonance frequency of the noise the basic machine is producing. Eliminate the source of the noise rather than making other parts heavier and heavier.

6. Stiffen edges of sheet-metal panels by folding them over.
7. Check run-outs of pulleys / couplings, etc.
8. Maintain proper center distances and PCDs in gears. Do not jam gears into each other, nor run them with too much backlash. Backlash in gears should be barely perceptible but not zero.
9. Timing belts produce a whine at high speeds if the pulleys are cut with low-quality hobs, or with hobs whose profile is theoretically incorrect.
10. Properly designed and maintained brakes and clutches should not squeal at all. Glazing on the lining can simply be taken off with emery paper.
11. Much of a good compressor noise is the intake noise. Cleverly mounting a car's or a truck's air-intake filter in place of the OEM filter reduces that to negligible levels. The same can be used to muffle noisy vacuum pump exhausts.
12. An anti-vibration mount is just that! It prevents machine vibrations (not air-borne noise) being transmitted to the ground, and to a very small extent, it dampens structure-borne noise. It is not a solution to heavy noise problems.

Anyway, nowadays the discos and the city roads are noisier than the factories. Noise levels are being measured in most cities, yet most current models of 3-wheelers are being most callously designed and manufactured with no regard to their gross noisiness. The same goes for domestic food-processors and industrial blowers. Who cares?

However, the first prize for the most enduring (but most inaccurate) noise goes to the sound of any and all gunfire in all Indian movies: *Ddhisshhkkyyaaauuunnn…* Have you ever heard gunfire in real life? It sounds exactly like those small Diwali crackers going off: putt… putt… putt… And the prize for the most unendurable noise goes to the "tension" scenes on current soap operas. Dhuddum Dhuddum Dhuddum Dhuddum… I would rather be in a power-loom shed with 500 old dobby looms running together.

Bund karo yeh bakwaas! Tuum aakhir chupp kyun nahin rah sakte Harsh?

Kyunki writer *bhi kabhi* listener *thaa!*

Next Month: Avoiding Overdesign

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Harshwardhan Gupta's Design Tips–14

Avoiding Overdesign

We Indians overdo everything in our lives! Look at our weddings, festivals, politics, interiors, houses, movies, soaps, food, travelling, corruption… As a people, we really don't know when to stop.

I have given various tips for avoiding overdesign in various past Design Tips, especially in # 3: Saving on Weight (IPF January 03), # 4: Saving on Raw Material Costs (IPF February 2003) and # 8: Saving on Energy (IPF June 2003) besides others. I don't want to repeat them. So, lets talk about this Deity called Safety Factor, before which every designer must pay his/her respects everyday!

Most of our indigenously designed machines are grossly overdesigned, unless they are ditto-copied from some foreign design. "Copying fully safe no? If 6mm pin works there, it should work here also! I am having full faith in reverse engineering sir!"

I think before proceeding I must legally caution you:

So be witnesseth that it shall hereinafter be Expressly and Mutually agreed upon that the Reader Present as Party or Parties of the Other part including and also not excluding whomsoever Absent before whom these Matters have been reduced to the Writings and thus heretofore has come to be placed before the Reader Present now hereby be Informed that the Author of this imputed Article styled and titled as "Avoiding Overdesign" in the allegedly popular and deemed to be well-circulated monthly and additionally annual Magazine having its name and masthead styled as "Industrial Product Finder" and also of aforementioned Writings and all his legal Heirs and Executors stand ab-initio Automatically and/or Consequentially in-toto Indemnified ad-infinitum of all claims towards any and all damages including those caused to any Third Party or parties not hereinbefore named if any ever arising notwithstanding and pursuant of subsequent Actions of the aforewarned Reader Present by this hereby Notice and Disclaimer if said Reader Present fail in any manner to apply all or part of the Following Recommendations with due Over-Diligence and abundant Over-Caution not heretobefore impugned so whereof by the affixation of hand I as Author and Affiant have declared and executed!

There, I have covered my backside now with this overdesigned legal clause! I am totally safe!

That's the whole point! How much of this omnipresent "Safety Factor" is rational, how much of it is lack of knowledge, fear of getting it wrong, laziness, contempt for your employer, and how much of it is a device to cover one's backside?

I'll give you a real-life example: I once saw a "robust" 6-station visual inspection table of 1 meter dia designed to carry 4 Kg connecting rods, with a pick-and-place mechanism to load and unload, rotating (not indexing) at 1 rpm! It was made from 30mm thick (for rigidity no?) MS plate covered with a 10mm rubber sheet. The table was supported on a thrust bearing of 150mm bore, not the light 51130, but the heaviest 51430. It was directly driven from below via a 1 hp motor driving a worm box of 1.5 hp rating, which drove another worm box rated at 1.5 times the rated output torque of the first box since a single reduction could not reduce the speed by 1400:1. This gearbox had an upward pointing 100mm dia output shaft that drove the turntable through a massive coupling! The whole contraption weighed around a ton! Moreover, the table was so high the inspectors had to sit on high, uncomfortable stools with no legroom.

Now, the 51430 thrust-bearing's static capacity is 180 tonnes! And the final worm box's output-torque is 1800 Kg-M. This can actually support and rotate a locomotive on its turntable at one rpm! Indian Railway's heaviest loco is only 145 tonnes.

How did this come about? I did some detective work. The designer started with an 'adequately' powered motor: Put one hp no? Sales have committed already bhai! Competitors were giving only half hp. Customer should not feel cheated! And Sir also said no put sufficient power? Ok? Ok! Next, go by the book: all transmission elements should have at least 1.5 times the capacity of driving element, so first gearbox should be 1.5 times capacity of motor, second gearbox rating 1.5 times first, coupling 1.5 times second gearbox! Then for such heavy table shaft should be also rigid no? 150mm dia seems OK, why take chance? Table should not dance no? Bearing also Sir said don't use light grade, Boy. Sir has worked in England you know! He calls me Boy only, never calls me Shankar! Anyway, radial load is negligible, so thrust bearing alone should be okay. And machine is going in forging industry, man! Evvrything is heavy built! You have seen knuckle bearing of their trimming press for this con-rod? Aishwarya Rai can pass through the bore, man! You should design all pucca, no lightweight things here! If anything happens tomorrow who will be responsible, tell me?

I know this is an extreme case, but not an exception at all! It happens all around all the time to different degrees. Lets learn our lessons from this real-life case:

1. Don't overdo the basic specs: Because you have to 'crack' the competition, your marketing whiz kids make up extravagant specs – mine is bigger than yours! Needless to say, you are putting cracks in your own profits.
2. Acquire basic engineering commonsense. Once you have put a safety factor of 1.5, (I would work with 1 in this case), you don't have to compound it!
3. See that your starting point is not wrong. Safety factor on what? The specification of 1 hp by itself is grossed by a factor of 10! Just 80 watts can do this job – 1/4th hp if you want a standard 3 phase motor. A pity that we still don't make smaller frame sizes. Even this motor would not be overloaded because of such heavy reduction, so you can underrate the gearboxes too.
4. Have a sense of scale. Two cheap 100mm bore tapered roller bearings back to back could take that entire load and more. A truck wheel runs on bearings even Aishwarya can't put her slim hand through.
5. Think laterally. Look for parallels in a different context. Have you seen the drive of the turntable of an old-fashioned gramophone record-player? Doing a similar thing would eliminate the bigger gearbox and that fat coupling altogether!
6. Scale everything to match. If the drive and loads are so light, why have a 30mm thick steel plate? 8mm can do, with some stiffening. Now if table and drive are so light, reduce the frame sections to a sensible size, ISMC-100 instead of ISA-100x100x16?
7. Have an overview once you have done the basic detailing. In this case, have pity on the real users and lower the table top sufficiently and provide legroom, so they can sit comfortably.
8. Rein in your electrical designer too! Their idea of safety factors is worse than us mechanical simpletons! They start with the thickest possible wire their pet fat connector can take, and then chose a make or type of cable that gives the fattest insulation for that fat bundle of copper wires. Then there will be secondary and tertiary insulation if you mention the word 'multi-core' or 'flexible conduit'! "No, no, no, no, no, no, we can't reduce anything! Everything is all as per standard only!" Nothing short of a blowtorch or masonry chisel can cut through their armour, literally and figuratively! (Sorry sorry, I used the word 'short', really sorry yaar! Oh my god, I also mentioned 'armour'! Now I have to multiply everything by 6, because everything better have armoured cables and IP65.) I have actually seen 150mm thick cable bundles going into ordinary packaging machines. No one ever realizes that the electrical guys need the least of safety factors, as they work with an overdose of safety devices anyway – fuses, fail-safe contactors, MCCBs, ACBs… and what have you. You think I am overreacting? Just open the control panel of a recent European or Japanese machine.

9. Understand the concept of MCA- Maximum Credible Accident. In this overdesigned monster, what can go wrong? Can something fail or crack in this engineering marvel? Never! Therefore, that is an incredible (impossible) accident, so don't provide for it. Simply put: don't design against accidents that cannot credibly happen! So, what can credibly happen at worst – in other words, what is the maximum credible accident possible for this machine? Well, if someone's fingers got stuck into the fixtures, he would be dragged into the pick & place and lose life or limb because nothing can stop that monstrous gearbox. When that happens, don't be a cad (no pun intended) and say, "I had given emergency button no, why didn't he press it?" Oh-ho, so you need an overload clutch also, no? No! Instead, just scale the drive down to a few watts, and make it a friction drive like I said above. If something gets stuck, the table stops spontaneously without any fancy sensors and hardware and controls!
10. And finally, have the professional courage to stand in front of your safety factor, not hide behind it.

And we still make unsafe machines, despite habitually overdesigning.

Abey lalloo! Safety factor *se panga nahin lene ka, samjha kya? Kuchh lafda ho gaya to woh &%$#@ Gupta tere ko bachaane ke liye aayega kya?*

Next Month: Ergonomics

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Harshwardhan Gupta's Design Tips–15

Ergonomics

Simply put, ergonomics is the science and art of designing things to suit human users.

We Indians live in an ocean of bad ergonomic design. Sadly, almost all good ergonomic design seen in our country is of foreign origin. Better than nothing, but much is not suited to us. There is an amazing lack of awareness and knowledge about this field even today. Easier said than done! Much of ergonomics is commonsense… which is not common, and all that…

It is the professional and ethical duty of all designers to keep ergonomics above all other considerations, and ensure that the interaction between their design and its final user does not become unpleasant, difficult to use (difficult to reach and clean too), confusing, tiring, illegible, unintelligible, mistake-prone, harmful or dangerous even in the smallest possible way.

This too is easier said than done. In developed countries, much of ergonomics is well-codified in laws, standards, guidelines and publicly available research data. We have virtually nothing of the sort! This puts a damper on all genuine efforts to make an ergonomically better design. Many engineering colleges are now teaching Ergonomics, but in a very superficial sense, and as a part of the industrial engineering course, not the machine design course! "Why you need ergonomics in machine design course, tell me?"

Many of you have visited Europe, America, Singapore, Japan… the developed world! The rest of you have heard glowing accounts of "everything is sooo nice there!" Do take a moment to realize that what you are appreciating is not just public cleanliness, aesthetically pleasing surroundings, and trains running on time, but are also subconsciously appreciating the good ergonomic designs all around – even though they are done for the locals who are marginally different from you physically.

There are two approaches to make an ergonomically sound design. First approach is that you go by the book and design everything by available standards! But virtually no good books exist even today on how to do good ergonomic design! Much of the available human body measurement data (anthropometrics) is predominantly derived from tall, strapping American army recruits by American industrial engineers for American designers! The other standards are from the great Henry Dreyfus (for the average American), or there are Japanese standards – more suitable to us, but solly not available in Engrish, Designer San, Gozaimaste!

The other approach is that, in the absence of anthropometric data, you should try and do good ergonomic design through a practical, eyes-wide-open commonsense approach. You have to evaluate your work objectively, starting with defining the faceless user. Too many real people are too often too obese, too short, too inexperienced, too old, too stiff, not intelligent enough, not educated enough, are just infants, or very curious children… and too often they are people with imperfect eyesight, arthritis, back-aches, knee-problems, orthopedic collars, allergies, pregnancies, liver problems, diabetes…

The Japanese and Koreans use their own ergonomic standards to design (say) a car, which explains why their seats are more comfortable to us than the ones designed in Europe and America. Also explains why cell-phone buttons are too small for us (East Asians do have smaller hands than us.) Lesson? Everybody designs things for themselves! And since we do not care about ourselves (as collectively, we are not perceptive and demanding consumers), absolutely nobody cares about ergonomically developing things specifically for us Indians, whatever their (and our) advertisers may say.

This 'American GI-Joe' centered anthropometry also explains why most dining tables (copied from the West) are too high, corporate-executive chairs slowly give you spondylitis, 'imported' sofas are too deep, sports shoes are too narrow, car steering-wheels are too high (especially for Indian women), Kitchen platforms are too high "You are not tall enough, Mrs. Joshi!", shirts of correct collar/shoulder size are too narrow on the chest, International 5-Star hotel spoons are too big, electric switches are too awkward, branded nappies are too wide at the base, most lathes and milling machines need a high platform in the front for the operator to stand, most power-tools cannot be operated by Indian women, first-class aircraft seats are horribly deep and economy-class one's are designed for aliens from Mars…

The bad ergonomic designing is not entirely confined to wrong dimensions. Severe engine-vibrations can slowly ruin a rickshaw / taxi / truck driver's kidneys. Daily 8+ hours of work on a keyboard is already producing orthopedic syndromes, as the standard QWERTY keyboard is the World's worst ergonomic design! There are no national standards for road-signs in India. Most wall clocks cannot be read from 15 feet away. Text on most medicine packs cannot be read without a magnifier by anyone beyond 35. Diabetics cannot get calorie information on food packs (1 in every 12 Indians is a diabetic now). User instructions in Hindi or regional languages – first written in English and then translated – are undecipherable even to a linguist…

A handful of organizations like the Indian Railways, Godrej, Tata Motors, Mumbai's BEST (buses), do make their seats /chairs quite Indian-user-friendly. Yet Indian Railways still fly in the face of all safety research, and believe that more uncomfortable the train driver's seat, more alert he would remain. Recent design changes in locomotive seats only upgrade them from sadistic to pathetic!

I am not playing impossible-to-please here. I am trying to point out glaring instances of bad design to you, so you as a designer don't contribute further to people's miseries. Some tips for you:

First, define your users, and see to it that your design is suitable for 95th percentile (95 out of 100 users), meaning you need not design for 3 feet tall dwarfs, 6½ feet tall *lamboos*, 32 Kg anorexics and 200+ Kg fatties, yet you have to take the middle 95% seriously. And your assembly / servicing / repair guys MUST to be included as a special category of users too! "See again this fellow is going full tangent!" Also remember that the buyer / consumer may or may not be the ultimate user – your wife buys a mop and your housemaid uses it.

Inadvertently, do not end up discriminating against large groups of the population – such as women, children and old people – by designing something only *jawaan* males can handle. Like our ¼-turn twist-lock lids for jams, honey and coffee jars! Once my-daddy-stronnngest closes them with his routine strength, no one else in the whole household can open them till daddy comes home again.

Do not go against prevalent conventions – like making MCCBs operate the other way – up for on and down for off. (Yes sir, I know the technical reason for this, but it can be gotten around by redesigning.)

A 'nice-looking' design is by no means a good ergonomic design, and vice versa. Unfortunately, many industrial designers – more conversant in ergonomics than machine designers –are often more preoccupied with aesthetics than with ergonomics.

A good ergonomic design is a safe design too, by definition; but vice-versa is not always true. Fool-proofing is just a small ingredient of ergonomics. Beyond jig & fixture design, not much of it is practiced in India! Child-safe packages for medicine / household cleaners / pesticides, and child-safe electrical hardware do not exist in India. "Keep out of reach of children" in fine print is sufficient to keep the manufacturer out of reach of the law.

If children are going to come in contact with your design – say of a kitchen cabinet system – then you have to play the role of the child BEFORE you play the housewife. Go down to their exact eye level and you will see a different world. And think like a child – they will scramble onto a trolley with castors and bring it down upon their heads, crawl into narrow spaces and get stuck, or pinch their tiny fingers, or lock themselves in, in ways you can't normally imagine. So, design against all such possibilities instead of blaming the poor mother.

If you are evaluating your design by putting yourself in the shoes of the user (a desirable method), you must always bear in mind how far away you are from the average. To wit, if you are

6' tall, then while designing / evaluating you must bear in mind you are 7" above the average Indian male and 10" above the average female, and therefore have longer arms, legs and bigger hands too. It's an extremely common mistake to unwittingly believe that you yourself can stand for the Average User!

You should never ever let machine-design conventions, styling, aesthetics, graphics, decoration, 'outlook-improvement', etc., take precedence over sound ergonomics.

If your marketing guys are the ones who are getting design feedback from the user, 9 times out of 10 they will simply pat their back, or yours if you are the boss. Indian marketers are talkers, not listeners; and the Indian user will rather suffer in silence than plainly tell a big company's representative that their product needs to be designed better, as that person will invariably argue back and put you down. Even if he does listen, that feedback will almost never translate into design changes. So, get a qualified team to conduct scientifically designed consumer research to reveal design flaws. Gathering of ergonomic feedback cannot be given on contract to call centers or to door-to-door teams – or worse – to camera-teams. "Hii I'm Shrutii and we are in Mumbaai with our cameraman Guddu and we are going to ask all these wonderful people here about how they like Futura's brand new Turbomate vacuum cleaner excuse me ma'am please tell us ya please take the mike and now tell us your name and please tell our viewers *aapko yeh* Futura *kaa naya* Turbomate vacuum cleaner *kaisa laga*?" will only get you what you'd love to hear. But detailed, patient, probing questions like "Is this specific vacuuming accessory easy to mount? Is it too tight to remove easily after use? Does it come off during use? Can your maidservant break it by 'normal' careless use? Does it reach everywhere you want it to reach? Are any protruding metal parts too sharp? Can it fit the wrong way? Is your healthily-curious 6-month old toddler safe around the running machine…" will bring in loads of nasty surprises! The wise king's tale comes to mind, who used to go anonymously in the evenings among ordinary citizens, disguised as an ordinary man, and chat with them to find out their opinions, problems and their king's shortcomings. Nowadays we are just given to posturing in this age of acceptable lies, brassy publicity and political correctness. "But now it is too late no?" Obviously, get ergonomic feedback **before** launching the product into the hyperbolic orbit of advertising. In Western Europe, a new model of practically every product is a definite ergonomic improvement over the last one. In India, usually only the advertising claims become taller!

And lastly, if you have made even a few users unhappy, don't try to shift the blame on them for their ignorance, lack of physical perfection, clumsiness, lack of education, etc… That's the refuge of the self-centered, self-righteous, self-justifying, self-opinionated, arrogant designer.

Plain and simple – if your have distressed the user, you have failed! Period!

"*Kya* boss, have you (hic), have you noticed that all liquor bottles, all Indian, foreign, (hic) all so easy for opening and holding when you pour no? I noticed today only, man! *Ekdum* Besht design! I am *toh* (hiiic) phully satisphied! Hey, common (come on) *yaar*, common common, bottoms up!"

Next Month: Machine Safety-1

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Harshwardhan Gupta's Design Tips–16

Machine Safety-1

This Article is in two parts; the first dealing with machines, and the second with automobiles, as the latter are now very commonly used machines – though we often do not think of them as machines.

Industrial safety is a big issue now, and many progressive companies are addressing this issue with vigor. Signs like "292 (or whatever) days without accident" are a common sight now. There are safety teams, safety audits, etc., and machine guarding and operational safety are being given their due place in these factories. This is also good IR.

In the more invisible, mundane of factories, squalor and lack of safety still reign supreme – although there is increasing pressure from their multinational customers to clean up their act. This still leaves a vast number of those factories that supply to an unorganized sector, and here industrial safety is still an alien concept. Losing one's life and limb is an occupational hazard the workers are forced to live with. Their bosses are often willing to "make settlement" through whichever way costs them the least.

What can the machine designer do to contribute to machine safety in such circumstances? Little, but not so little either!

In a new design, when it comes to safety, deciding on what criteria would define a safe machine is the foremost task. Our laws on this point are very lax, varied, outdated, and most of all unclear and open to a vast range of interpretation. For a few specific machines (like boilers, lifts, etc.), the safety regulations are quite comprehensive, yet outdated and very poorly implemented. For example, in an 'approved' lift with the common 'scissors type' collapsible shutters, a child can put his hand through the shutters and get his arm torn off. "Parents should have taken care no?"

Some developed countries like Germany and the US have very sensible and comprehensive safety laws and codes like CE and OSHA, and very well-implemented too. Some others like the UK swing to the other extreme, and make the laws so stringent, amounting to this, that however hard one tries to injure oneself, one should not even end up injuring just his little finger. (Lesson for machine exporters here – be clear about which code to follow.)

In Design Tips 14, I had written about the concept of Maximum Credible Accident (MCA) in the context of over-designing of machine parts. Same concept is to be applied in machine safety too. The designer must take into account the MCA, and design for adequate prevention.

A big area of concern is electrical safety. In this area, ELCBs (earth-fault circuit breakers – things which put the power off the moment you get a shock) are a big help, but their use is not yet mandatory. Faulty old wiring, often chewed into by rats, combined with improper storage so often results in all sorts of accidents.

Another big area is fire safety, and except in a few well-designed factories, fire-safety, use of fire-retardant material, fire escapes, fire doors, etc., are merely topics of sterile debate. The most ill-placed and neglected piece of equipment in an average factory is the pathetic little fire-extinguisher. The use instructions on these are works of contemporary abstract art. Hardly any research has been done on their legibility, comprehension and effectiveness in an emergency. The other extreme is the sexy little domestic fire extinguisher – without any printed instructions whatsoever! I personally know of a case of incorrect (but well within the domain of commonsense) use, where the user got very badly burnt when she used it on an otherwise controllable frying-pan fire.

In factories, fire drills are being implemented sporadically, but only time will tell their effectiveness. Fire departments do not have powers to enforce fire safety measures, and building / factory inspectors, who do have the power, do not have requisite specialized training – "Sir what to do, we are not having proper guidelines only we have written many times to superiors that public is demanding action nowadays!" They are exceptionally well-trained and creative in certain other kind of demanding… No further comments! "Collector blames systemic failure for tragedy, promises action against erring officials after proper inquiry" says a tiny news brief on page 12.

One can go on and on, but the machine designer, system designer, plant-layout designer, electrical system designer, building designer / architect… all must put themselves into the shoes of an accident victim and design against such things happening. There is one specific area I wish to elaborate on – and that is machine guarding and associated safety interlocks. A widespread belief still exists among designers that, "What's the use? Users will dismantle and bypass them anyway, and cost will also increase no?" This defeatism must go now. There are ways to mechanically fit things in such a way that they cannot be tampered with. Even door switches can be made tamper proof. Further safety can be written into the PLC or other software, which can monitor the operation of the door switches and disable the machine if they are electrically bypassed.

Safety is a state of mind. Having said those six words so easily, one has to translate that into operational terms, beginning with the designer. The user must change his mindset too, and recognize the human cost of accidents. Putting up safety posters to educate and organizing safety seminars is necessary but not sufficient. Our very mindset must change.

A huge majority in India still persists with this fatalistic attitude – that one cannot change one's Destiny! This is simply not true. Lives can be saved, and are being saved everyday in the World by design and more careful design, not by God's wishes. Have you seen the car crashes in Formula One races shown on the TV? The zooming car crashes and explodes into a nitro-methane fireball, and a moment later; the driver just walks out of the flames and mangled metal – no injury!

God's will? I don't think so – every bit of that car was thoroughly and consciously designed in such a way that it would save the driver's life in a massive crash at phenomenally high speeds!

"My upstair neighborer that Ram Kumar you met no died last week in accident in his factory you know! Hospital they took him immediately within 1 hour. Doctors tried level best but no use. Tottal Sai Baba devotee he was you know, evvry year without fail visiting and morning evening pooja! I tell you God's will nobbody can change! What safety audit safety training sir, all this safety shafety no any use when Time comes! Whattever you do, when Time comes you have to go sir, nobbody can save you sir, nobbody!"

Yaar aaj-kal mera bhi bad-luck kharaab chal raha hai.

Next Month: Machine Safety-2

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Harshwardhan Gupta's Design Tips–17

Machine Safety-2

Automobiles are machines that all of us use every day. However, often we do not think of them as machines. It is instructive to know that in Italian, *macchina* means a car; and in exacting German, it's not flight LH-152 that lands at Frankfurt, it's the *maschine* (the aircraft) on flight LH-152 that lands at Frankfurt! So, *Signore e Signori,* lets talk about safety in your *macchina:*

India has the highest rate of casualties per vehicle-km in the World. Today it far surpasses our industrial casualty figures – hence this article:

1. Do you know that your car's door-lock is a safety device before it is a security device? Almost all of today's cars have their door locks designed (by foreigners) so that they don't let the door burst open in a crash, thus the passenger space resists buckling, and saves lives of the occupants. If they are not locked, they fly open, and this protective shell collapses, literally squeezing out passengers' lives. The many glamorized auto-&-bike TV programs make no mention of this. Even user's manuals do not tell you this. Such a simple action can save hundreds of lives. But no one cares, not even the insurance companies or the Loss Prevention organizations. Nobody even researches this simple matter – what percentage of car crash deaths is due to unlocked doors bursting open?
2. Ditto with seat-belts! So many people don't even know how to put them on! In so many cars, you keep fumbling for the seat-belt's well-hidden bottom latch. Different seat-belts, even in the same car, lock at widely different pull speeds. Majority customers don't know and don't care. The RTO's or the Police don't care either. In UK, I have ridden in cars that won't even start till all doors, boot and hood are locked and all occupied seats' seat-belts are on. The wiring for this is ridiculously simple, but this is not available in India.
3. Same with crash helmets. All are made to a fixed size! If your head is bigger or smaller or the wrong shape, and your crash helmet doesn't fit well, that's your headache. ISI doesn't specify sizes, nor defines a comfortable fit over long periods. Then we have the misdirected Champions of Individual Freedom clamoring for repeal of the Helmet Rule, and succeeding too – probably because even the best of helmets are so horribly uncomfortable to so many!
4. Major auto manufacturers have themselves been resisting the introduction of power steering in medium and large trucks, citing flimsy reasons. That alone would prevent many large vehicles going out of control on curves or in tight traffic situations. Many small cars that do not need power steering are offered with it as a luxury add-on!
5. Wheel alignment for trucks, (I am yet to see a truck on an alignment machine) wheel balancing, radial and tubeless tyres for trucks, truck cabs on secondary suspension for less fatigue – all contributing to better safety, are all alien concepts in India.
6. Air-bags are offered only on luxury sedans! You can't buy them for smaller cars. No move yet to make them compulsory.
7. Speed-breakers are neither properly painted, nor are as per standards! No templates available to check them.
8. Most of today's cars have a low front, and a common accident is a car going under a truck's high rear-end (front and sides too), and the car's top and passengers' heads getting severed. A couple of states now require an anti-tailgating bar behind the truck, but most you see are sloppily fabricated contraptions just to avoid the cops, not scientific designs at all - truck-body building being a cottage industry! No special chassis are designed for tankers, lowering their center of gravity to make them less prone to rolling over.
9. Bus-body builders, especially for state-owned

buses, merrily cut corners by raising the bottom edge of the bus's sides, thus making the gap between the road and the bus's side-skirt high enough for pedestrians, passengers getting off, and two-wheelers to get rolled under the killing wheels.

10. Most of our buses are nothing but houses erected on a lorry chassis. On the contrary, the new Swedish-designed Volvo buses (not their imitations) have integral chassis-less one-piece bodies, like a car's, and are designed to protect passengers in a crash. Additionally, if all the passengers are provided with (and asked to) wear aircraft-type seat-belts in these integral buses, they can actually walk out of virtually all crashes. The same crash would reduce a normal bus to a scrap heap, and kill almost all.
11. Many 3-wheeler and van designs are certified to be roadworthy, but no one designs them for or tests their crash-worthiness. No norms for crash-worthiness exist for any vehicle in Mera Bharat Mahaan. A Ralph Nader is yet to be born in India.
12. The basic vehicle designs are tested and certified by authorities, but what about the completely unregulated market of external accessories? Fancy tubular chrome add-ons for your bumpers are outright dangerous for your vehicle plus for whom they ram into. Even a minor crash will not only damage your original designed-for-safety plastic bumper, but will cause invisible damage to the frame, leaving it grossly unsafe in a major crash. Many car and 3-wheeler outer accessories snare pedestrians or two-wheelers, and drag them to their deaths, or simply slash and gore. The metal 'sun-shade' over the Ambassador windscreen, an accessory favored by many government cars, can slash open the skull of anyone who gets into a glancing collision with it. Matching rear-view mirrors mounted just behind the headlights can rip your intestines out at 30 kmph.
13. "Break failed *ho gaya*!" When a bus tumbles down a gorge with 60 passengers because an old embrittled brake-hose burst open or a cheapo banjo seal bulged out of its seat, we write it off as 'break-fail!' "Happens! It is machine only." In the industry, we incessantly talk of preventive maintenance, MTBF, genuine OEM parts, Safety First culture… and then leave our vehicles in the hands of incompetent, badly-trained cheap mak-niks. Well, if you pay peanuts, you only get monkeys! Nevertheless, many Authorized Service Centers employ equally poorly paid but even more incompetent diploma holders in automobile engineering! Auto maintenance is so often a sharp business deal rather than a scientific exercise.
14. Talking of brakes, virtually no 2-wheeler's manual tells you that the *front* brake must be used primarily. When you brake either wheel, the load on, and so the road-grip of the rear wheel decreases, and that on the front wheel increases. Harder the braking – more weight and grip transfer from back to front. So if you brake the *rear* wheel hard, it can easily lock up and skid on the road, leaving you with insufficient gyroscopic balance, thus spilling you on the road within milliseconds. This weight-transfer phenomenon is classic physics, but is absent in all physics textbooks. Unknown to most, cars usually have their brakes designed for 80% braking in front, and 20% in rear. This habit of using the rear brake in 2-wheelers stems from the cockeyed front-pivoted suspension designs of many models, where the front suspension takes a vicious dive if the front brake is applied hard, sometimes cart-wheeling the rider right on his head onto the road in front – so we were told to always use the rear brake.
15. And what about the design of marketing strategies? Watch the auto and bike ads (made by our 'socially responsible' media) again! Virtually all of them tell you the same thing in different ways: Ride ever more rashly with our sexy machine! Go faster, Faster, overtake now, NOW! Enjoy the Adrenalin Rush, the Unbridled Power, the Roaring Speed! Unleash the ferocious beast inside you! Go, Go, Go, shine before the girls! Girls, don't drive, just fall in love with the rashest, most Macho, most reckless! Guys, brake hard at the last moment and put the rear wheels in

a controlled skid (on some TV ads unreadable warnings come and go *flup,* like a flashbulb)… And now the tyre companies and the petro-PSUs too have joined this grotesque war-dance – Fit my tyre and race a fighter jet! Fill my fuel and ride the wild buffalo! Why should I drive defensively, when the WHOLE hyperbole-enabled reality-challenged media circus is constantly screaming at me to do exactly the opposite, relentlessly insinuating that defensive drivers are cowards, frightened old men, flaccid nerds, nobodies!

But tell me, why don't they advertise other man-things like oxy-acetylene torches or pneumatic chisels or hand-held power drills or machining centers in the same way? Here: Unleash the power of your main spindle's torque-boosted VelociRaptor 27hp Tri-phaser drive! Zoom from 0 to 8800 rpm in 6 seconds flat! Chew up and spit out that defiant chunk of steel below, maxing out with your multi-edged Shuriken cutter! "You are mad or what? Those are just some kind of machines only. These are veekles, man! You know in ancient time man used to love his horse no? So now it is his car or bike he love same way!" Yeah? Horses are intelligent animals and they don't trample people, even if you goad them to. 'Veekles', however sexy, are deaf, dumb, blind, enormously more powerful, and completely brainless. Why ban tobacco ads when car, bike, tyre and fuel ads promote instant suicide and/or manslaughter!

16. And design of systems to educate + test drivers on safety techniques, road-craft and defensive, considerate driving? Who can bell *this* cat? For love or money, you cannot buy a book or VCD on defensive road-craft on Indian roads. What road-craft? If you ask to overtake a truck from the right, its driver flashes his RIGHT indicator – a 'convention' among truckers – to indicate that you can now pass him from right! More educated drivers flash the left indicator to signal the very same thing! Yet, the same trucker flashes that very right indicator if he is going to turn right and block your overtaking.

17. What about design of nationally standardized, visible, legible, understandable, weather-proof road-signs? Have design institutes like IDC and NID been commissioned to work on these problems?

18. And design of life-saving systems? Once you are in a crash, people will instantly surround you and enthusiasts among them will tug and pull your broken body out any untrained how, often causing even more injuries. Now, even if an ambulance comes quickly, has it been designed and equipped to extract and rescue road accident victims? How many people die horribly because most emergency rescue systems cannot reach anywhere fast enough? And neither the police nor the paramedics have necessary equipment & training to extricate victims from mangled metal, not even a simple hacksaw! Some primitive tools are indeed carried by the lumbering tow-truck, but it always arrives last. "Fast-aid training is given to all our police peoples and all jeeps carry also. See, fast we do *panchnama* and try take out injured party, crowd peoples also help, only if complete imposeebal then we call control room for *kiran* (tow-truck), then they send it message, then it comes. This is corret proseejar!" But can you even give any meaningful first-aid to that poor gasping, bleeding, dying guy without first quickly and safely extracting him from the mangled wreck? "Ok, ok, yes that may be also importan sometime I think! But never we received complaint like that, why only you come with complaint? Who you?"

As is so common, we consider it our sacred duty to obstinately resist any change for the better. "Go Slow, Work is in Progress" so that we can see India rapidly become a developed nation by 2020 – provided we don't first bleed to death somewhere on the road!

"Guptaji why you are always taking so much tension yaar? At least population is reducing little bit no? Hee, hee!"

Next Month: Problems of high speeds

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Harshwardhan Gupta's Design Tips–18

Problems of High Speeds

What works at 10 per minute, doesn't work at 35 per minute. What works at 35 per minute, doesn't work at 100 per minute. What works at 100 per minute, doesn't work at 300 per minute. In my observation, every tripling of speeds entails a complete sea-change of concept. The 'sensible' argument of preferring 3 'simple' machines of 1/3rd speed and 1/3rd price doesn't always work out nowadays, as the cost of space, power and (competent) manpower is increasing, and machine reliability is going up too. Unfortunately, designing conceptually-original high-speed machines from absolute scratch is one capability we woefully lack in India.

"You know such high speed machines all sophisticated high-tech but very problematic. We cannot achieve such speeds it is very danger. Our slow machine only is best." Not really! As I have said before, high-tech is nothing but attention to detail. Higher the speed, more thoroughly the designer must understand the theory and predict the behaviour of his whole concept in totality. Faster the machine, more detailed must be your design and drawings, and more precise. When you conceive the machine in your mind, you should picture the running machine – not just a static mechanism – and think how the motions, forces, inertias, momentums, vibrations, and machine elements will behave at those speeds.

"Give us *pukka* tips Sir-*jee*, not these ronnd ronnd words *jee*!" So here:

1. Gravity does not change with speed, so if something is intermittently fed by gravity into the machine, its fall time must be reduced: firstly, obstructions and sliding friction removed, and if possible, falling height reduced, so the fall takes less time. To reduce falling time to half, falling height has to be reduced to 1/4th. Not possible? Then force it down with a positive drive of some kind.
2. 3-phase AC motors can be started and stopped only so many times per hour as specified by the manufacturer's catalog, or they overheat from repeated inrush of high starting currents. So either use a bigger motor, thus de-rating it (this also increases rotational inertia), or use an electromagnetic clutch-brake (usually jerky and unpleasantly noisy), or force-cool the motor externally – uncommon but best!
3. Followers are leaving the cams as you run the machine faster? "Some loud *khata-khat* noise started coming at higher speed sir so I slowed again." Use closed-profile cams, where there is one cam surface on each side of the follower, like a groove cut in a plate or a cylinder. Now you don't need springs. Use thin, high-penetration rust-preventive oil. If you lubricate these with grease, you will only create an abstract sculpture in grease.
4. Fast pneumatics needs careful understanding and design. Put thinnest possible tubes from the valve to the cylinder, use smaller switching valves and thus try and avoid flow-control valves. Put the valves closer to the cylinder. Use faster switching valves. Use cylinders with end-cushioning. If the stroke of a 100 bore x 300 stroke cylinder should take 1 second, you don't have to put a huge 1/2" solenoid valve with fat, stiff 12mm tubing and then choke it with large flow-control valves, making everything sluggish. And is that 100mm bore really required? A hard look at the application might show you that even a 25 bore cylinder would be sufficient! Many machine-designers (we generally are a very insecure breed) believe that bigger is better, except in cell phones! Try forcing back a 25mm cylinder at 6 bars (30kg force). You can't! "Oh-ho, so much force is there, is it? I thought an average 70kg person can easily force a 25 bore cylinder!"
5. Shack-abjer… sorry, shock-absorbers are wonderful devices and they allow you to run cylinders faster than you otherwise can. Go by the book and choose the proper joules-per-stroke AND joules-per-hour rating – else you will bust them.
6. And don't use shock-absorbers as dead-stops – dead-stops have to be in parallel with the

shock-absorber. Similarly, don't use any kind of switches as dead-stops either.

7. Check your PLC. Older/cheaper PLCs work slower in processing the logic, and if it is a complex, fast cycle, then quite unbelievably, the slow PLC or even a convoluted design of the logic can make a huge difference. In the electrical engineers' mind, microprocessors work instantly, programs run through in nanoseconds. In reality they don't, especially if the logic has been written by somebody who says yes to everything. The best of system houses can easily go off on a total tangent and completely drown the job in slow speeds, and then obstinately blame the 'mak-nikal side'. "Problem was coming sir, but see I slow down the motor problem is gone…" Don't forget that you have committed for high-speeds, they haven't. "Basically Gupta sir doesn't like electrical engineers yaar, *samjha karo na*!" Nothing of the sort, but politics cannot solve electrical deficiencies.

8. Needless to say, make moving parts light, compact, and yet rigid… Come out of the casting-and-steel-plate mindset and explore sheet metal, plastics, tubular sections, etc. Parts can be made rigid by geometry also, not just by adding metal. Chamfer, cut and drill away unnecessary material.

9. For very high-speed machines, try and do things in continuous motion, and use less of pneumatics. For example, cartoning machines, processing small, soft and flimsy paper cartons, till about 100 cartons per minute, work with intermittent motion for the carton. But 300 cpm machines work with continuous motion of the carton. Form-fill-seal machines work fine with intermittent motions up to 40 packs per minute. 100 ppm necessitates continuous motion of the film. The whole concept, design and construction changes.

10. Servomotors, even today's stepper motors, are very versatile and can do a lot of things AC motors or pneumatics cannot do. Still, one should avoid over-specifying the motor size and should make sure that the electronics would definitely keep pace with the requirements. Many electronic designers are not attuned to think that way either. They think that 20 milliseconds response time at every logical step is very fast, if not same as instantaneous. "Scan time is onnly 100 microseconds, sir!" Then the solenoid valve takes 22 milliseconds to respond, contactor coil takes 40ms, clutch-brake takes 120ms… If you speed up the pneumatic cylinder, it starts hammering. If you increase the end-cushioning, the piston starts bouncing back. If you put a shock-absorber, cycle time goes up. So, this is where you have to change tracks, discard old ideas, think and design carefully, and avoid and bypass the problem, rather than fighting it. Beyond a certain speed, you have to go mechanical and do everything with linkages and cams… "Hmmm, that means we will have to copy that Germany maseen we saw in Hanovar Agjibisan. I already took out detail propojal from them with drawing. Our old pneumatic was so simpal (sigh) Sunil can you not make it work somehow?"

"*Haan-jee*, jast one more tip *jee* Sir-*jee*, make it nice ronnd figure *jee*, lakky alaven *kaar do*…"

11. Run with the machine, as I say, and imagine what will happen in real time. When you draw it out, don't get stuck with the static drawing, and don't just think of the motions alone, think of the speed too. This may sound obvious, but I have seen many designers get trapped in the static drawing. 3D real time simulations are too complex, too expensive to build, and I can tell you 'hundred and ten percent' that they are no substitute for a real prototype of your high-speed mechanism. And when things move too fast for the eye during the test run, get a strobe light – the best friend of the high-speed automator.

Duniya, yeh duniya, Toofan Mail! Iske pahiye zor se chalte… "Ai to vadda puranna ganna hai jee, aj-kaal toh jee yeh music-shoosic *bhi ekkdamm balle-balle* spper faast *chall rya hai! Mai keya Gupta-jee aaj-kaal* life *hi kitni* spper faast *ho gi hai!"*

Next Month: Surface Treatment

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Harshwardhan Gupta's Design Tips–19

Surface Treatment

This is not a standard informative article about conventional and new surface treatments. There is plenty of 'what' and 'how-to' information available on that. (Most authoritative is the ASM Metals Handbook, latest edition, volume on surface treatment – expensive but worth every paisa) As is usual in this column, I will go into some of the little-known facts, prevalent misunderstandings and usual screw-ups that are common in the normal gamut of surface treatments. Surface treatments are done for appearance, corrosion protection, or to get certain surface properties like wear-resistance, or all of these. This is the domain of 'The Good, the Bad and the Ugly'! *"Dekho phir se iska* shining *maarna shuru ho gaya!"*

Lampooning aside, do be informed of one aspect of corrosion in steel: Excess, or plentiful oxygen will deter corrosion. Limited or trapped oxygen will accelerate corrosion. Unbelievable? Believe it! Pneumatic valves and cylinders merrily work for years without corrosion on their plain steel parts, as so much oxygen (in the air) is always churning past them. Steel screws in blind oil-less holes rust within a few days as oxygen is trapped in the blind hole. Square bars lying on dry floor rust on the bottom only, where air cannot circulate freely. Bare steel parts washed with thinner, dried and sealed in plastic bags rust in a few days. *Sochne ki baat hai.* Oxygen starvation leads to more corrosion in steel, not less. This is one of the quirks of nature: you can't fight it.

People with long experience of using or providing specialized treatments usually know their field, so these tips are for the average user. *Hamaare* experts *ne khaas aapke liye banaya hai!*

1. Natural steel: Most steels require some or the other surface treatment, else they will merrily rust. Machine-tool design is one area where the machines generally work in a perennially oily environment – so bare steel does not rust there. Hence, machine tool designers often leave steel parts bare. Similarly, gearbox inner parts, since they are always immersed in oil are not treated for corrosion protection. Now when their designers step into other areas like material handling, packaging, etc., they simply don't bother to specify surface protection. So please don't forget to specify surface treatment for steels!
2. Pickling: Remember ordinary pickling will not remove weld burns or mill-scale (the gray-black oxide film present on hot-rolled steel).
3. Blackodizing or blackening: This is a porous finish which adsorbs (not absorbs) oil, and will prevent rusting only when it is wet with oil at all times. Blackening and oil only give protection together – oil alone or blackening alone is no protection. Blackening does not change dimensions. High hardness or alloy content results in a reddish gray color; not black – so don't start screaming on the vendor. If you clean blackened parts with solvents like kerosene or thinner, this will remove this oil film, and rusting will start within a few hours. Wrapping blackened parts in newspaper will also draw away this oil, and the acids in the paper will immediately cause rusting. Use plastic film to wrap blackened & oiled parts. The oil used for dipping by the blackening vendor is quenching oil, and is often very badly oxidized. The free acids thus produced in that oil cause corrosion despite all above precautions. In such cases, wash the received blackened & oiled part with mineral turpentine or kerosene or diesel oil, wipe dry and again apply fresh SAE-40 oil immediately.
4. Zinc-plating / dip galvanizing: Zinc plating is the cheapest and best protection for steel. Blue, green or yellow passivation protects the zinc, which protects the steel. Dip galvanizing is extremely durable but gives a very thick, uneven coating. Best for outdoor, dirty or watery applications. Common detergents eat away zinc very quickly (so don't wash your car with household detergents). Zinc is electronegative so small scratches do not

cause rusting.

5. Cadmium plating: Better than zinc but more expensive. Never use it in pharma- and food-processing machinery, as it is toxic. It is also electronegative.

6. Electroless Nickel: More expensive than cadmium but electropositive, so any discontinuity will result in rusting. Color is difficult to control. Applied without any electric current, it gives a very uniform layer thickness all around compared to any other type of electroplating. Electroless Nickel plating drastically reduces the coefficient of friction, so it can easily make screws and nuts come loose even under mild vibrations. Spring washers will cause rusting where they bite into the base part.

7. Phosphating: This is a very porous coating, used to increase adherence of paint. It can also be used for lubricant film retention (in gears, etc.), or for avoiding welding of surfaces under high local loads. Used by itself, it needs a heavy oil film to protect the steel. Unless its acid is thoroughly washed off, it can start corrosion.

8. Hard chrome: Most hardened steels and spring steels are prone to hydrogen embrittlement, resulting in the chrome layer flaking off. This is directly deposited, and is different from bright chrome, which is chrome plating on nickel-plating on copper plating on steel – thus building up quite an unevenly thick layer.

9. Glass-bead blasting: Evident from the name – blasting not with sand or shot, but with fine round glass beads. Gives a uniform matt finish without scratching or gouging the surface the way sand or shot do. Used as preparatory finish for Electroless nickel or satin chrome, or as a matt finish on stainless steels.

10. Anodizing of aluminium: Do not try to anodize aluminium castings – the necessary high silicon content in cast alloys will ruin it. Do not buff machined parts before or after anodizing (see below). Do not bead-blast either – the resulting part will become very prone to stains. Anodizing does not alter size.

11. Buffing: *Chamak ka dost*, quality *ka dushman*. Buffing distorts and ruins all geometric accuracies of the part. Use bead blasting and flash-chrome (thin hard-chrome) instead. This gives a very durable, attractive matt finish, and is popularly called 'satin-chrome'. Bright-chrome with buffing is the most abusive treatment of machined (not sheet-metal) parts, and it implies poor quality and carelessness to a discerning buyer. All that shines is not gold, as the saying goes.

12. Electropolishing: Running the job on the anode. It removes high spots at a microscopic level, and gives a far cleaner shiny surface (seen under a microscope) than buffing. Best for medical, food and pharma applications, as the microscopic smoothness results in a bacteria-resistant surface too. It takes a skilled plater to do a good job.

13. Painting: Hammertone finish paints imply poor quality, and suggest an attempt to hide poor basic finish. The need to clean, de-rust (best is the brushing-type phosphating solution) cannot be overemphasized. Please don't try to cut corners by avoiding the primer coat. And please paint your machine parts <u>before</u> assembly, not after! The latter again conveys carelessness. Don't tell me that you can carefully disguise that, as anyone with a sharp eye can catch you right away, and then you convey an even worse image of your quality. Alternately, don't attempt to paint beforehand, and then 'only' give one final coat after assembly – that also is obvious to a discerning eye. If you want your product to look like some wonderfully shabby Indian Railways equipment, then follow their dictum – 'If it moves, lubricate it generously; If it doesn't move, paint it liberally'. The ubiquitous aluminium paint used on oven and furnace exteriors is often put without any special treatment, and the surface below starts rusting within weeks. "Excuse, sir, for paint and rubber parts, company not giving any gerantee!"

14. Hydrogen Embrittlement: Running the job on the cathode makes the job absorb the hydrogen ions which are also attracted to the cathode along with plating metal ions.

Hydrogen ions are nothing but high-velocity protons, far smaller than even the tiny hydrogen atom. These penetrate deep into the material, just like bullets, then gain an electron and become immensely larger, thus stressing the metal crystals, making the metal brittle. Plate a circlip and see for yourself how it snaps off as you stress it for mounting.

15. Plating in holes: No electroplating will enter holes, as the electric field there is very weak, unless you put a specially designed bar anode in the hole itself. Electroless nickel will enter holes too.
16. Traditional Marathi wisdom says very rightly, *Ati tithe maati!* Excess leads to perdition, to downfall! Excessive plating thickness, excessive plating current density, excessive pickling, excess production from a given bath, excessive buffing, excessive paint thickness, excessive electropolishing, will all lead to ruin!
17. All the same, keep away from platers who will take out the part as soon as it has got 'color' all over. And if you yourself have insisted on ultra-thin plating at ultra-cheap rates, then you yourself are on your road to perdition!

Do not use ANY surface build-up treatments (plating, painting) in these situations:

a. On rolling bearing elements of any kind – including shafts on which steel balls, rollers or needles are running, and even on steel wheels on steel rails under high loads. Any build-up treatment would either flake off (chrome) or wear out soon (zinc), and ruin the bearings.
b. On stainless steel, except surface removal treatments like polishing, bead blasting, electro polishing, and texturing – like brush finishing.
c. Where close tolerances must be maintained. Unfortunately, no commercial electroplater will give you consistent thicknesses. So, watch out for uneven, unrepeatable plating layer build-up. If you specify tolerances before plating, you are damned, and if you specify them after plating, you are doomed. Blackening and zinc plating are safe to use as blackening does not build up any thickness, and excess zinc gets burnished or peeled off during tight assembly.

For all our global aspirations, you can still buy all sorts of brand-new "*peti*-pack" industrial maseens / missions / mesheens: lathes, shapers, milling machines, large motors, compressors, power hacksaws, pillar drills, bench grinders, machine vices, surface plates, you name it ("In small items full thermacoll pecking is coming sir!") – liberally smeared with ugly daubs of tacky "rust preventive" creosote oil on wherever there is bare steel, with plastic sheets stuck on, and the whole machine unceremoniously tied into more layers of plastic sheets just the way a corpse is bundled into cloth, packed in a damp termite-eaten wooden coffin lined with blotchy tar-paper. Rest In Peace!

"*Sanwla rang aur* oily skin*?* Pimples *se pareshaan hain? Chehre par kaale dhabbe? Naina-ji, aapne* zinc-plating *try kiya? Sirf doe dinon mein hi paiye kamaal kaa goraa-pun!* Belt-sanding *aapke* pimple-marks *jad se mitaa degaa,* pickling *aapki twacha ke dhabbe door karegaa, aur* yellow-passivation *aapko degaa poora* humidity protection*! Aur yeh sub kewal saat rupaye* kilo *mein! Ab* marks *se* no marks! *Ladke waale bus dekhte rah jayenge!"*

Next Month: Gears

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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 with 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 3x3x3x3 (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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