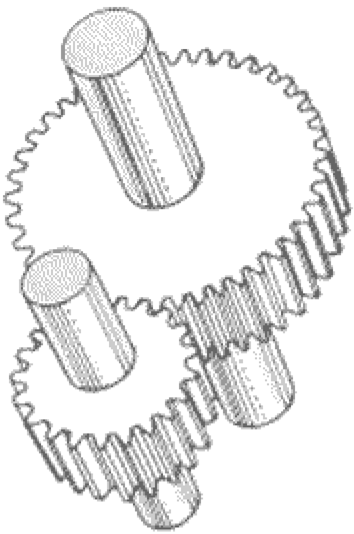
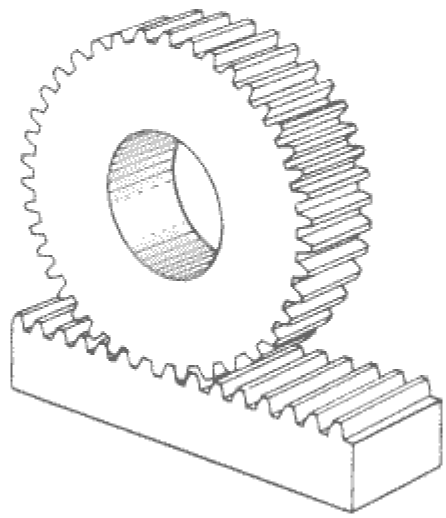
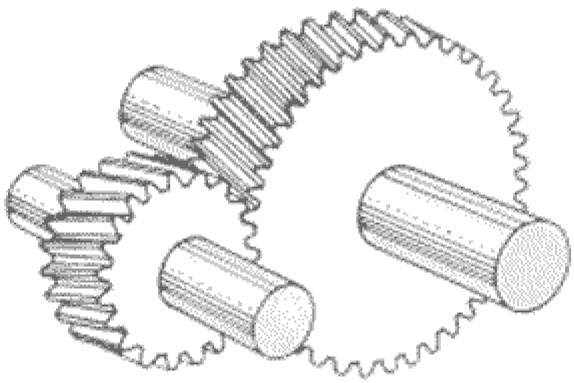
1st Quality DR Gears

Gear Graphs





A Guide To Interpreting The Squiggly Lines



Resolve the many causes of Errors in Hobbing and Shaving by unlocking the information in Gear Graphs

A DR Gears Technical Publication

v1	1996	Lecture material (VB)
v1.2	1996	Added further graphs
v1.5	1998	Added & updated causes
v2	1998	Changed base media (IL)
v2.2	1999	Hard copy version available
v2.5	2001	Updated animations
v3	2003	Re-write and update
		Add index search
v3	2004	Publish PDF version

A DR Gears Publication

Contents

1. Introduction

Problems incurred during gear manufacture can be frustrating and often a time consuming experience. Transmission error and gear noise are a fact of life for some, but **Why?**

Today, we have the most advanced CNC Gear Metrology machines available, capable of measuring gears to very exacting standards. These machines present us with a sophisticated array of colourful graphs and endless streams of data, all indicating that we have a good gear **OR** a Lead Error **OR** a Profile Error **OR**, **AND**, **ALSO**, etc. etc.

This is fine, but as yet these machines do not tell us which operation, process, tool, nut, bolt or washer is responsible for the errors they find. This we have to interpret ourselves.

Scenario: A component is submitted for one of its scheduled inspections; the gear inspector puts it through the inspection machine and is presented with graphs and data that have areas of **RED!** “Sorry it’s failed” he remarks, “What's wrong with it?” enquires the machine setter. “Probably the cutter”, the inspector replies.

The machine setter changes the cutter, the old one sent for regrind (probably unnecessarily) and the whole procedure is repeated. More **RED** graphs, another vague suggestion, another cutter change, etc, etc. Sound familiar?

There are **many** companies whose gear inspectors have been responsible for this kind of service.

Without the ability to interpret the information given by these machines: ~

YOU HAVE THE MOST EXPENSIVE GO - NOGO GAUGE IN THE WORLD!

It is to help with this situation that this manual has been produced. By explaining the graphs and indicating the causes, it enables you to get to the **Root Cause** of the problem thus saving you time and money by reducing unnecessary DOWN TIME.

David Robinson

2. The Basics of Errors

2.1. What is an Error?

The end result of Gear Errors is well documented - Transmission Error - Gear Noise

So what exactly is an error?

"An error is an error", I hear you say, but this presents us with a huge area of confusion.

Without understanding the types of errors we can encounter and the areas from which they may evolve, when it comes to problem solving them:

- We have no starting point
- We have no direction
- We are definitely a long way from a result

By getting back to basics:

- We have defined a starting point
- Direction becomes clearer
- We are well on our way to a result solution

Let's start our basics by understanding the types of errors we can encounter and how we find them.

Gear inspection and the errors it finds, fall into two main categories: ~

ANALYTICAL & FUNCTIONAL

2.2. Analytical Testing

'Determining various attributes with measuring devices'

Analytical gear testing comprises of various methods that check dimensional characteristics of the gear. These include lead, profile, runout, tooth spacing (indexing/thickness) and tooth surface finish.

The manufacturing process often requires limits on these attributes and sometimes deviations from the limits. Gear inspection using analytical methods can determine the accuracy and identify when it is necessary to make adjustments to the process.

Analytical measuring methods vary from the use of a gear tooth vernier for chordal tooth measurement or span micrometers for base tangent tooth measurements to CNC gear metrology machines (CMM's) that can do a fully automatic dimensional inspection in one setup.

The machine in FIG.1 is the SH450 from Frenco International. This type of machine uses a base disc that is equal to the base circle diameter of the gear being measured.

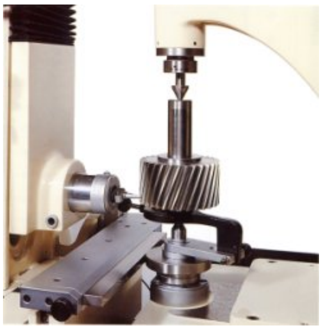


Fig.1: **SH450**

The machine in FIG.2 is the Euro 500 from David Brown Gear Metrology; this is a radically new CNC Analytical Gear Tester using state of the art technology with a revolutionary new design. The aerostatic bearings provide non-contact motion to all axes resulting in no wear. The controls are in a familiar windows environment.

Fig.2: **Euro 500**

Analytical gear inspection comprises of various methods to check the following characteristics: ~

LEAD	*A Helix Angle Error.* It has the appearance of variation* and/or irregularity*. It can be influenced by misalignment, taper, crown or hollow.
INVOLUTE	*A Form Error.* It has the appearance of variation* and/or irregularity*. It can be influenced by the tooling, setting or runout.
RUNOUT	*A Setting Error.* It has the appearance of variation*. It can be in a radial or axial direction.
TOOTH SPACING	*A Pitching Error.* It has the appearance of variation* and/or irregularity*. It can be influenced by the tooling or the machine.
TOOTH SURFACE FINISH	*A Surface Error.* It has the appearance of variation* and/or irregularity*. It can be influenced by the machine, material or setting.

* Variation: Follows a pattern
* Irregularity: Does not follow a pattern

2.3. Functional Testing

'Determining various attributes when the gear is in motion or under load'

Functional gear testing consists of testing gears by the way they *function* or roll.

The rolling of gears to test their quality can be done at any stage of production, using anything from the simple roll tester to the elaborate noise machines that listen to the harmonics of rolling gears.

One of the most common in-line testing machines is the Roll Tester; this gives fast, reliable results that are required by today's modern gear production methods.

The machine in FIG.3 is the R125 from Frenco International. The gear being checked is rolled in tight mesh with a master gear and a dial indicator shows any discrepancies.

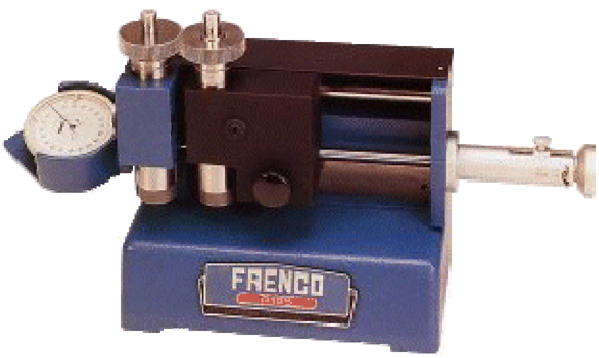


Fig.3: **R125**

Other versions include a motor drive, transducers and computer control with an easy to use Windows interface; this will trace a graph through a full revolution of the test gear and store the results for statistical analysis.

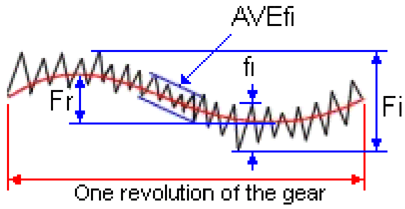


FIG.4: **Graph showing typical output from a roll tester**

The data in this chart can determine: ~

Fi - Total Composite Error
fi - Tooth-to-Tooth Composite Error
AVEfi - Average Tooth-to-Tooth Composite Error
Fr - Runout (averaged)

Functional gear inspection comprises of various methods to check the following characteristics: ~

TOOTH ACTION

A Noise Error.
It has the appearance of variation*.
It can be influenced by ALL transmission errors including profile, runout and damage.

2.4. The Cause of Errors

Errors can originate from many areas of the manufacturing process: ~

Gear Blank - this may be machined out of tolerance or incorrectly set on the machine, or maybe damaged on the locating surfaces (nicks and burrs).

Workholding Fixture - incorrect setting of the fixture or damage to its locating surfaces. A light rub with a fine carborundum stone should be used to check for nicks and burrs before assembly. By lightly passing the stone over the surface any damage will be felt, the damaged area **only** can then be worked eliminating the removal of metal from a wider, undamaged area. The fixture may also be insufficiently robust allowing flexing under load *(see **Set-up**)*.

Gear Cutting Machine - the machine may be incorrectly set-up or just in need of maintenance. Consider the possibility that the wrong type of machine is being used, i.e. it may be underpowered with insufficient hp for the pitch and metal removal, or working beyond the extremes of its capacity.

Tooling - incorrectly ground or damaged tooling, wrong specification and/or class of tooling.

Set-up - the whole set-up needs to be robust enough to ensure rigidity, speeds and feeds need to reflect this and also take into consideration the age of the machine, tooling and component material.
There is also the problem of ***Lack of Human Perfection***.

Component Material - this may be too hard, too soft or have impurities and imperfections in its structure.

Inspection Equipment and/or Method - your component may be perfect! Check that the inspection equipment is within calibration working to a defined calibration schedule. Ensure you are using consistent datum's throughout manufacture **and** during the inspection process.

Cutting Oil - this must be of sufficient flow and not misdirected from the point of tool and component contact. Does it have the correct chemistry for your gear material/tool configuration?

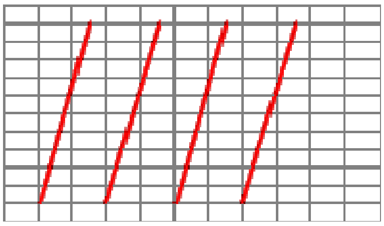
3.

Hobbing Graphs

Notes:

3.1. Lead

3.1.1. Parallel

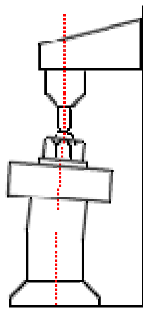


1. INCORRECT LEAD GEARS ON THE HOBBING MACHINE

Ensure that the correct gears are used for the Lead (spiral/helical gears). Also ensure they are installed correctly on the machine and in the right order. For example; the gears designated as *driver* are used in the driving shafts and the gears designated as *driven* are used on the driven shafts.

2. THE ACTUAL RATIO OF INDEX GEARS IS NOT CLOSE ENOUGH TO THEORETICAL RATIO

Error between theoretical and actual ratios should be in the 6th decimal place or better See GeaRatio. **Any** error in these gears will create a ± condition in the number of teeth, i.e., after each revolution of the component, the number of teeth machined will be incremented or decremented by a small amount and this increases or decreases the lead in relation.



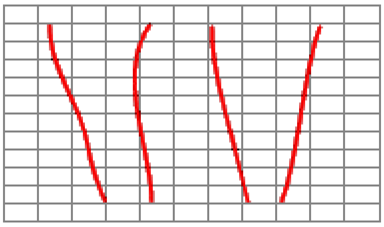
3. MISALIGNMENT OF THE WORKHOLDING CENTRES

This will cause distortion in the workholding fixture and accelerate wear in the tailsupport centre and bearings. Check the runout of the fixture without tail support, then engage the tail support and check for deflection.

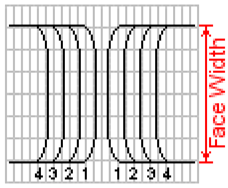
4. LOOSE GIBS ON THE HOBBING MACHINE TABLE

The gibs are strips of material between the moving part of the machine and the slideways. They usually have a very slight taper and located on one side of each slideway. By adjusting, they allow the take-up of wear between the slide and the moving part. It is also important that they are not over tightened as this can create premature wear; damage to the mating surfaces and cause irregular movement.

3.1.2. Variation

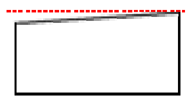


5. LEAD VARIATION



The difference between the measured (actual) lead and the specified (theoretical) lead. Typically, four teeth at 90° apart are measured on both flanks (measured in the normal plane) and then averaged. Planned modifications and helix deviations are recorded as departures from a straight line. The four-tooth average is used to help counter any discrepancies between the gear cutting and gear measurement axis.

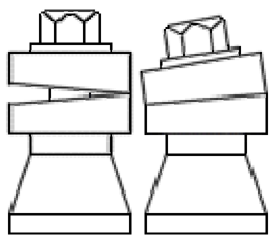
6. THE FACES OF THE BLANK ARE NOT SQUARE TO THE BORE



May be due to a miss-load of the component during any operation that defines a dimension, i.e. turning, broaching or grinding. Miss-loading can be due to: -

- Swarf - ensure parts are clean before loading; use an oil wash to the locating surfaces on machines with autoloaders and filtered coolant.
- Soft jaws - these may require re-skimming.
- Handraulic - hand locating by an operator must be done consistently and with care.

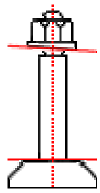
7. TOO MANY BLANKS CUT TOGETHER



The component may be within tolerance individually but if gearcut two or more at a time, small errors will be accumulated. If two components are to be gearcut together, tolerances of the mating faces should be halved. This will ensure that individual components, when machined at top limit, will not exceed the maximum tolerance when stacked due to **tolerance build-up**.

8. Faces of the Arbor Nut are not Square with the Pitch Diameter of the Thread

If this face is un-square it can bend the mandrel and deflect the component. This will cause both radial and axial runout of the component. The bending or ***bent-ness*** of the mandrel will become permanent due to material memory if this problem is not addressed.

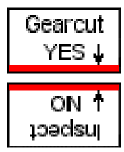


9. Worn Bearings in the Table or Tail Support

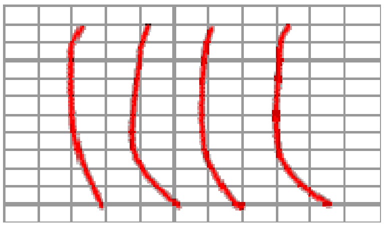
With wear in the table bearings, the fixture will runout in an irregular rotational pattern. Worn bearings in the tail support will allow the fixture to bend and flex when the component is under load from cutting pressure. Each problem will cause both radial and axial runout in the component, which in turn will result in lead errors.

10. Using a Different Datum Face to Check the Lead than that Used on the Hobbing Machine

The face turned at the same time as the bore should be identified as the **Datum Face** (often with a shallow groove) and used as a reference for all subsequent operations including inspection. A common datum should be maintained throughout all stages of manufacture.

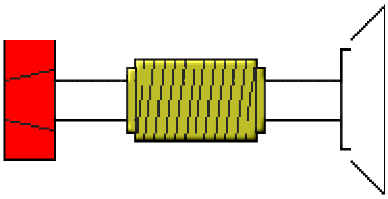


3.1.3. Irregular Tooth Surface



11. WORN BEARINGS IN THE HOB ARBOR TAIL STEADY

Insufficient support here will allow the arbor and hob to flex creating radial runout in the hob and chatter on the gear tooth surface. Any loss of rigidity of the hob will cause uneven hob tooth loading *(showing as chatter)* and premature wear.

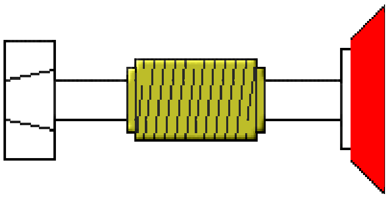


12. LOOSE HOB ARBOR TAIL STEADY

Ensure that the tail steady has been securely tightened. The mating faces between the tail steady and the hobbing head are prone to damage, this can be caused by the tools used when mounting or from swarf that can collect behind the tail steady and embeds itself in the mating surfaces.

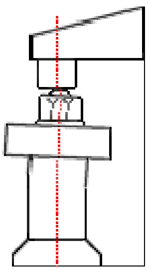
13. LOOSENESS IN THE HEAD OF THE HOB ARBOR SPINDLE

This can cause not only radial runout but also lateral movement of the hob. Any loss of rigidity of the hob will cause uneven hob tooth loading and premature wear. Adjustment of the bearings is often done by grinding a small amount off a spacing plate.

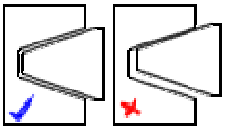


14. WORN BEARINGS IN THE WORKHOLDING TAIL STEADY

The fixture will flex under load and cause runout of the component in a radial and axial direction. If a centre is used, check for damage or wear to either the centre or the hole, also check whether the centre is bottoming in the centre hole.



15. EXCESSIVE BACKLASH IN THE LEAD GEARS



Backlash in an assembled gear set is the clearance or play between the teeth of the meshing gears. Backlash may be detected by holding one gear static and rotating the mating gear in each direction. Excessive backlash will cause kickback through the kinematic drive - maximum backlash should be 0.127mm(0.005in).

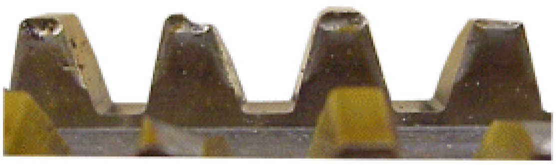
16. EXCESSIVE TOOL PRESSURE (FEED RATE)

This will cause the component and/or fixture to flex and bend. Undue strain will occur through the kinematic drive as the torque increases creating the movement to the left in the graph. Once all possible play has been taken up the lead will straighten until the hob starts to break out and the torque is lessened, the lead then moves back over to the right.

17. WORN GUIDEWAYS ON THE MACHINE

As the hob enters the component, the machine loading will find any wear or backlash and create thrust. In the graph, the hob is climb hobbing, as it enters and torque increased, wear and play is taken up, the lead moves over, as in the previous cause **(16)**, the lead then straightens until the torque is reduced as the hob breakout at the top.

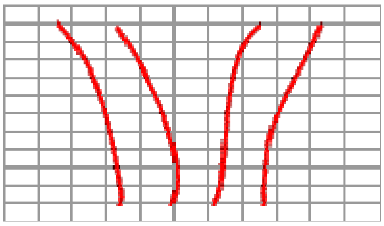
18. WORN OR DAMAGED HOB



If the cutting edges of the hob teeth are worn or damaged, the cutting action will be put under additional pressure, creating thrust away from the cutting edges especially from the leading edge. This condition will also accelerate premature wear of the hob.

3.2. Profile

3.2.1. Basic Involute Form



19. Insufficient accuracy in the hob (class 'C' vs. class 'A')

Scenario: - 'Somebody digs out an old hob from storage, notes it is the same pitch as the one being used and suggests it is used up to save money'. Specifications may have changed since that hob was manufactured and used.

CHECK THE SPEC!

There are four common classifications of hobs:

1. Class A - Precision ground
Class A hobs are a ground precision type used for finishing where no subsequent operations such as gear shaving or gear grinding are involved. Class AA, ultra-precision ground hobs are also available.

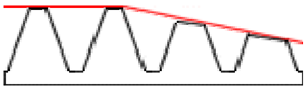
2. Class B - Commercial ground
Class B hobs are used for both finishing and semi-finishing prior to gear shaving or gear grinding. With Class A and B hobs, subsequent grinding operations are for refinement of the limits on profile, lead and spacing.

3. Class C - Accurate unground
Class C hobs are unground and most commonly used for semi-finishing. They are formed by **backing off** in an annealed state and then heat-treating. Except for the grinding of the bore, proof diameter and hub faces, no further refinement of the tooth form, spacing or lead is made.

4. Class D - commercial unground
Class D hobs are of commercial unground tolerances and used for roughing only.

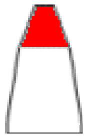
Most tool manufacturers are *geared* to produce **A+** class hobs and consequently may offer the best deals for this class of tooling.

20. CUTTING WITH A PORTION OF THE HOB THAT IS TOO CLOSE TO THE END FACES



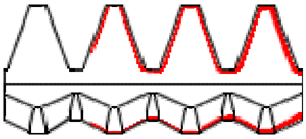
A taper is usually provided on the leading end of the hob teeth when producing helical gears. The shortening of these teeth eases the load on entry and prevents fracturing. As these teeth are not fully formed, you must not allow the gear teeth to go into this region on centreline especially during hob shift.

21. USING A HOB THAT IS GROUND BEYOND ITS ACTIVE LIFE AREA



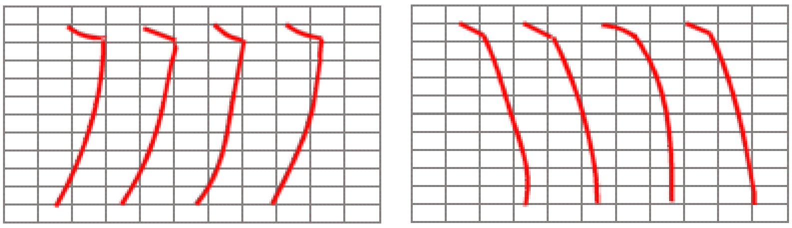
The shaded area is the unground relief. When resharpening the hob, care must be taken not to go beyond this point as the profile deteriorates.

22. HOB GROUND WITH A LEAD ERROR IN THE GASHES



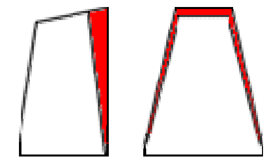
If the gashes are ground with a lead error, due to the spiral of the hob teeth, this will cause a change to the pitch, which worsens along its length. The hobbing machines hob shift will cause the production of gears in a batch with irregular size and profile.

Basic Involute Form *Continued*



23. HOB GROUND WITH A POSITIVE FACE RAKE

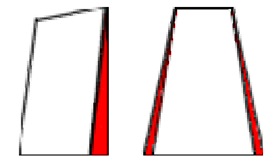
The pressure angle is increased. Reset the dressing diamond height on the hob sharpener and redress the wheel, then re-centre the wheel and hob.



Side View Front View

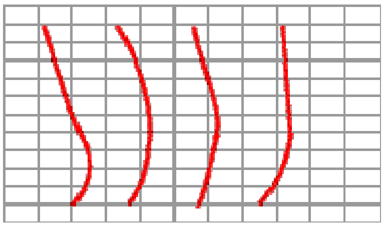
24. HOB GROUND WITH A NEGATIVE FACE RAKE

The pressure angle is decreased. Reset the dressing diamond height on the hob sharpener and redress the wheel, next re-centre the wheel and hob.

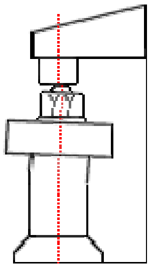


Side View Front View

3.2.2. Involute Form Variation

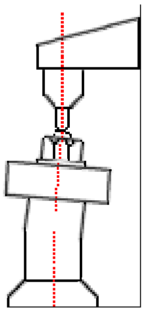


25. RUNOUT IN THE WORKHOLDING FIXTURE



Runout in the fixture will accelerate wear in the top support bearing or centre. Set the fixture true first without any top support, then engage the top support/centre and check for deflection.

26. MACHINE CENTRES ARE OUT OF ALIGNMENT

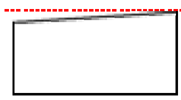


Check that the fixture is running true without the top support then bring the top support down, misalignment will cause deflection of the workholding fixture.

27. WORN BEARINGS IN THE WORKHOLDING TOP SUPPORT

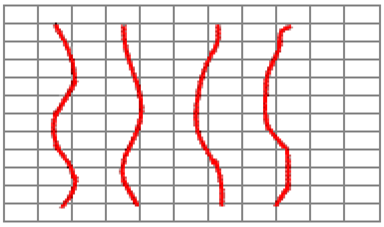
The fixture will flex under load and cause runout of the component in a radial and axial direction. If a centre is used, check for damage or wear to either the centre of the centre hole also ensures that the centre is not bottoming in the centre hole.

28. FACES OF THE BLANKS ARE NOT PARALLEL

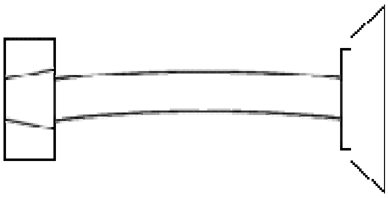


Ensure that parallelism of the faces is within tolerance and be aware of tolerance build-up when cutting more than one component at a time. Identify the datum face on the drawing and mark this on the component, this is often done with a small groove which is turned into the datum face. Use this datum face for all operations, including inspection.

3.2.3. Irregularity



29. HOB ARBOR BENT



Check the arbor between centres off the machine, and then check it at the same points in the hobbing machine. Non-parallel spacers may have caused the bending.

30. HOB ARBOR IS NOT RUNNING TRUE

Check for swarf between the mating faces or damage to locating surfaces. Check the bearings in both the tail support and the head drive.

31. NON-PARALLEL HOB CLAMPING SPACERS

The spacers may have been ground with non-parallel faces or the bore not square to the faces, there may also be foreign material such as swarf causing mis-alignment. Check also for damage such as nicks and burrs; a light rub with a fine carborundum stone should be used to check for these before assembly (by lightly passing over the surface with the stone, any damage will be felt, the damaged area only can then be worked on eliminating the removal of metal from a wider, undamaged area).

32. OVERSIZE HOB BORE OR UNDERSIZE HOB ARBOR

Diameters on the hob arbor may be worn; this will require replacement of the hob arbor. Check also for **metric** vs. **imperial** measurements (a metric size hob bore with an imperial size arbor).

33. WORN OR MISALIGNED TAIL STEADY BRACKET

This will cause radial runout of the hob and mandrel. Any loss of rigidity or runout of the hob will cause uneven hob tooth loading and premature wear.

34. HOB ARBOR NUT FACE IS NOT SQUARE WITH THE PITCH DIAMETER OF THE THREAD

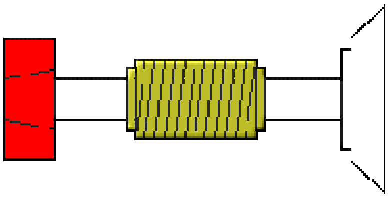
This will cause bending of the hob arbor and radial runout of the hob.

35. FOREIGN MATERIAL ON THE MOUNTING SURFACES

Cleanliness when mounting mating surfaces is of utmost importance. Surfaces should be cleaned and checked for nicks and burrs. Using a light rub with a fine carborundum stone any damage will be felt, the damaged area only can then be worked thus eliminating the removal of metal from a wider, undamaged area.

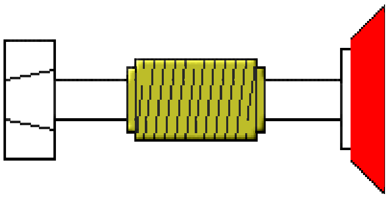
36. WORN BEARINGS IN THE TAIL STEADY

Insufficient support here will allow the mandrel and cutter to flex causing radial runout in the hob.



37. LATERAL 'END PLAY' IN THE CUTTER SPINDLE

Due to worn bearings in the drive head. This will cause radial runout of the hob. In some drive head designs; grinding a small amount off a spacing plate can often make adjustment.

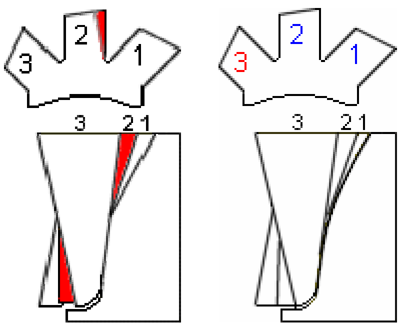


38. INCORRECT SETTING OF THE HOB HEAD ANGLE

If the head angle is incorrect, the clearance angles on the cutting edges of the hob will be reduced or eliminated causing possible push off from the cutting surface.

39. GASH TO GASH SPACING ERROR IN THE HOB

When a hob generates a true tooth profile, it is made up of a series of facets, 3 of which are shown here. In the first diagram (left), the teeth on row 2 (red) have a gash-to-gash error. This will not form a true involute on the tooth profile. In the second diagram (right) a profile is produced with no gash-to-gash error.



40. REFERENCE DIAMETERS OF THE HOB ARE NOT RUNNING TRUE

Fig A –maximum runout on the reference diameters should be:
0.012mm (0.0005") TIR* for rough hobbing (semi-finishing)
0.005mm (0.0002") TIR for finish hobbing
Any runout MUST be kept **in phase** between the two ends.

Fig B – the hob is running true, the graph shows slight undulations due to feed.

Fig C – hob runout is even both ends, the graph shows an **in phase** condition appearing as increased undulations.

Fig D – the hob is running out on one end, the graph shows an **out of phase** condition with increased undulations on the right flank but still slightly affecting the left flank.

Fig E – the hob is running out both ends unevenly, the graph shows an **out of phase** condition with greatly increased undulations.

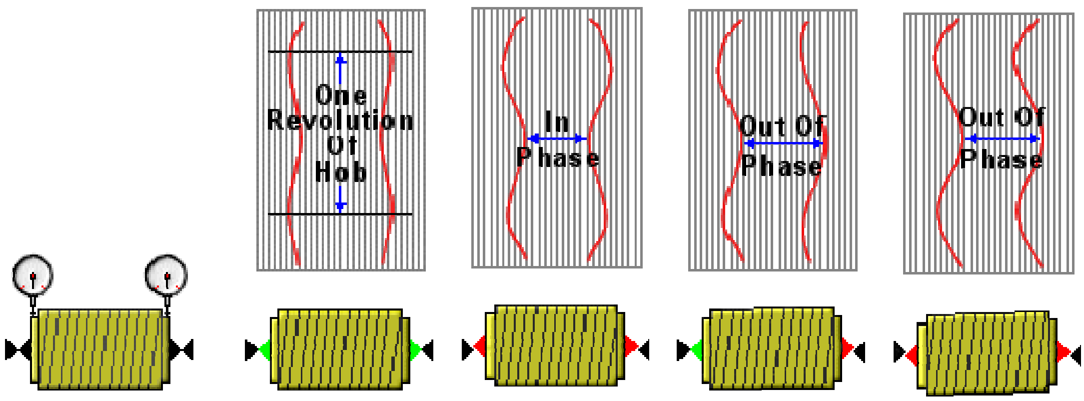
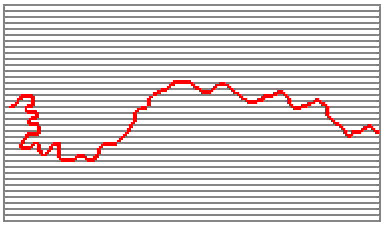


Fig. A **Fig. B** **Fig. C** **Fig. D** **Fig. E**

* Total Indicator Reading

3.3. Runout



41. RUNOUT IN THE WORKHOLDING FIXTURE

Clock (indicate) the fixture to ensure it is running true. Do this first without any support then bring down the support fixture and check for deflection. Any misalignment will quickly create wear in the bearings.

42. WORN BEARINGS IN THE WORKHOLDING TAILSTOCK

The workholding fixture will flex under load causing runout of the component not only radially but also axially.

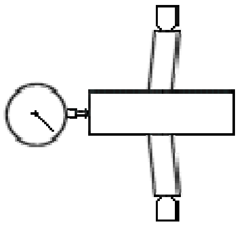
43. OVERSIZE BORE ON THE BLANK

Tight control of locating diameters on both the component and the workholding fixture will improve radial runout and reduce wear to the arbor of the workholding fixture.

44. WORN (UNDERSIZE) WORK ARBOR

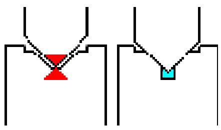
Do not rub down to make assembly easier; an accumulation of tolerances will cause component runout.

45. BENT CHECKING ARBOR



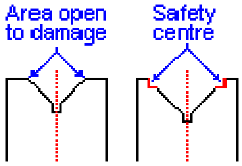
Check the arbor for straightness, surface nicks or damage to the centres. A calibration schedule should be maintained to ensure continued accuracy of the measuring equipment.

46. CENTRE IS BOTTOMING



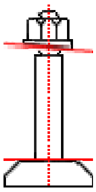
Ensure that the centre hole has a countersink clearance hole for the centre point to locate without interference. Check also that this clearance hole does not get blocked with swarf that could prevent the centre from locating fully.

47. DAMAGE TO THE CENTRE HOLE



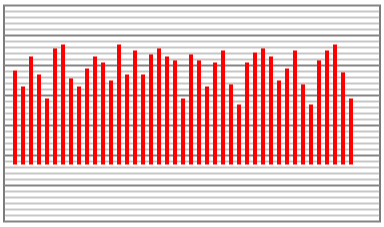
The centre hole should have a safety centre machined in the end to prevent damage to the edges.

48. WORKHOLDING ARBOR NUT FACE IS OUT OF SQUARE WITH THE PD OF THE THREAD



If this face is out it can bend the workholding mandrel and cause runout.

3.4. Tooth Spacing

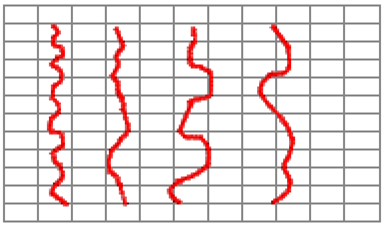


49. WORN OR LOOSE BULL GEAR IN HOBBING MACHINE

50. THE NUMBER OF STARTS IN THE HOB AND NUMBER OF TEETH IN THE GEAR HAVE A COMMON DENOMINATOR

More commonly called **Hunting Tooth**. This is where an extra tooth is added or subtracted usually from the wheel to avoid an exact ratio. One of the advantages of a **Hunting Tooth** is that it prevents a wheel tooth contacting the same pinion tooth each revolution of the wheel, thus distributing a more even wear pattern. One of the disadvantages is that if a particular tooth on both pinion and wheel has an error, then because they will come together at some time the error will be magnified.

3.5. Tooth Surface Finish

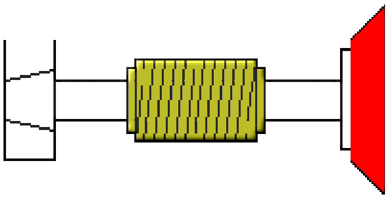


51. Malfunction of the feed mechanism in the machine

If the feed is intermittent it allows the hob to remove more metal in one area, check the clutch for slipping.

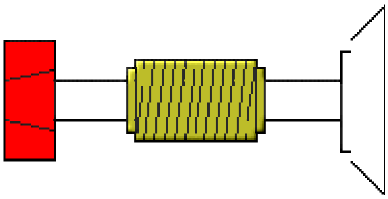
52. Worn bearings in the hob spindle

This will cause radial and lateral runout of the hob. Adjust the bearings, often by grinding a small amount off a spacing plate.



53. Worn bearings in the hob arbor tail steady

Insufficient support here will allow the mandrel and cutter to flex.



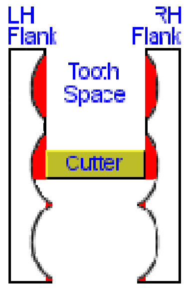
54. Looseness of the hob arbor tail steady

Ensure that the tail steady has been securely tightened. The mating faces between the tail steady and the hobbing head are prone to damage, this can be caused by the tools used when mounting or from swarf that collects behind the tail steady and embeds itself in the mating surfaces.

55. Parts not clamped sufficiently rigid

The component must be clamped sufficiently rigid to prevent flexing or chatter during the cutting cycle. Rigid support must be given almost to the root diameter.

56. INSUFFICIENT STOCK FOR THE FINISH CUT (2^{ND} PASS)



If the 1^{st} cut is too deep, the 2^{nd} will not clean up in the bottom of the serrations. It could also be seen as coarse scratches from a heavy feed on the 1^{st} cut.

57. HOB HEAD NOT CLAMPED TIGHT

Remember **Lack of Human Perfection**; do not allow pressure of work to cause possible forgetfulness.

58. CUTTER SPEED VS. MATERIAL HARDNESS

The correct selection of cutter speed for the type of material being cut is most important if the cutter is to perform as expected.

59. FEED RATE EXCESSIVE

This will cause the component and/or fixture to flex and bend. Undue strain will occur through the kinematic drive as the torque increases creating push off.

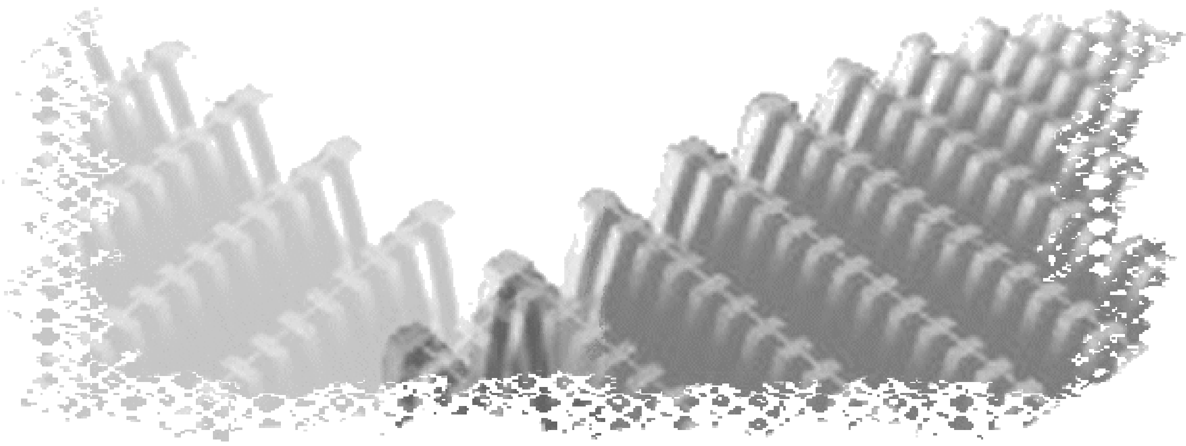
60. DIRECTION OF FEED (CLIMB VS. CONVENTIONAL)

The climb hobbing method usually gives a better surface and improved tool life. Since the hob teeth get well below the surface at the start of the cut, there is less chance of rubbing occurring at the tips of the teeth and the greater pressure occurs at a point a little distance away from the extreme edge. It is for this reason that climb hobbing is used for high-speed hobbing.

Notes:

4.

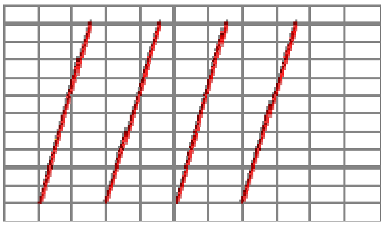
Shaving Graphs



Notes:

4.1. Lead

4.1.1. Parallel



61. CUTTER HEAD IS SET AT THE WRONG ANGLE
The head must be set to the shaving cutter lead angle.

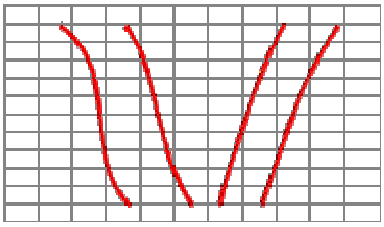
62. CUTTER HEAD ANGLE NOT ADJUSTED TO SUIT RESHARPENED SHAVING CUTTER
Each time the shaving cutter is reground, its lead angle will be sufficiently altered as to affect the lead of the component, the head requires an angle correction and the formulae below will help you accurately make a final adjustment.

$$\text{Dial Indicator Movement} = \frac{10 \times \text{Lead Error}}{\text{Length of face being measured}}$$

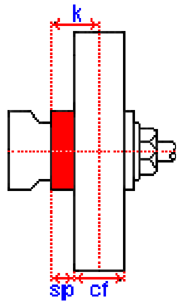
63. CUTTER HEAD CLAMPING NUTS ARE NOT TIGHTENED PROPERLY
Another case of **Lack of Human Perfection**, do not forget to final tighten after adjustment.

64. GEAR IS SLIPPING ON THE SHAVING ARBOR DURING THE SHAVING CYCLE
The clamping system must exert sufficient pressure so that the component is clamped adequately without slippage but not of such a force that distortion occurs.

4.1.2. Tapered Teeth



65. INCORRECT SPACER(S) ON THE CUTTER ARBOR



The spacer is one of a set that came with the machine.

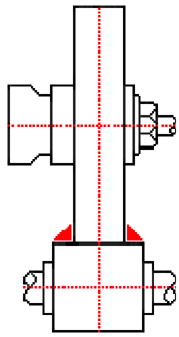
To determine the size of spacer:

$$sp = k - \frac{cf}{2}$$

Where:

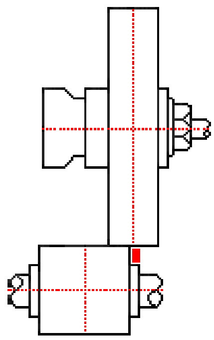
sp = spacer width.
k = constant (taken from the arbor face to the centre of the head).
cf = cutter face width.

66. COMPONENT IS NOT CENTRED TO THE CUTTER



After the cutter is centred to the cutter head, the component **must** be centred to the cutter.

67. UNEVEN LENGTH OF STROKE



The length of stroke should be approx. 6mm (¼") greater than the face width of the component and the end faces passing 3mm (⅛") past the centreline of the cutter each side.

68. TAPER ATTACHMENT NOT ZEROED

A setting bar that can be clocked (indicated) will permit the checking of alignment.

69. TAPER GROUND IN THE LEAD OF THE SHAVING CUTTER TEETH

Care needs to be taken during resharpening, as any error will be reproduced in the component.

70. MACHINE CENTRES OUT OF ALIGNMENT

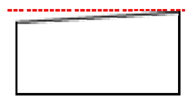
The setting bar suggested above will help determine this.

71. LEAD CHECKING MACHINE OUT OF CALIBRATION

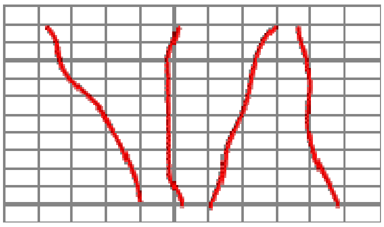
Your component may be within specification, check the inspection equipment’s calibration and calibration schedule.

72. FACES OF THE COMPONENT ARE NOT SQUARE TO THE BORE

Ensure that parallelism of the faces is within tolerance. Identify the datum face.

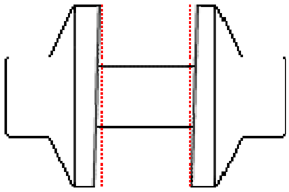


4.1.3. Variation



73. Locating surfaces of the shaving mandrel are not square to the axis of rotation

Regrind if necessary, also check for damage or wear to the centre holes.



74. Worn bearings in the head and/or tailstock centres

Regular maintenance schedules should be installed, as this is a common area of wear.

75. Checking arbor nut faces are not square with the PD of the threads

Will cause deflection of the component

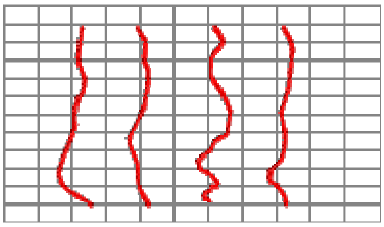
76. Mismatch between the gear ID and the arbor OD

Be aware of an accumulation of tolerances or just wear of the shaving mandrel.

77. Locating on a different surface to check the gear than one used to shave

A common datum throughout manufacture is very important.

4.1.4. Irregular Tooth Surface



78. LOOSE GIBS ON THE MACHINE

These are strips of material, often with a slight taper, that allow adjustment to take up wear between a slide bed and a moving head. Over adjustment can also have a detrimental affect.

79. LOOSE OR WORN NUT ON THE LEAD SCREW OF THE MACHINE

Due to the continuous rapid movement, back and forth, this nut could become loose or gradually wear.

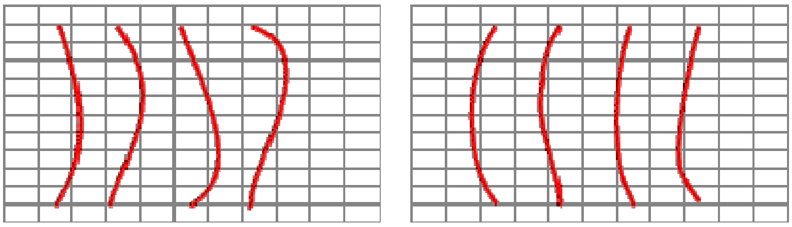
80. CUTTER NOT ROTATING AGAINST THE DIRECTION OF THE TABLE – *See Appendix 2*

The incorrect direction of rotation to direction of feed/traverse can affect quality and tool life.

81. LOOSE CUTTER SPINDLE

Check that it has been correctly tightened or that worn bearings are not allowing deflection.

4.1.5. Crown or Hollow



82. CROWN ATTACHMENT NOT SET TO CORRECT READINGS
If the Crown is correct on one flank, but to one end of the other flank of the gear tooth, it is necessary to adjust the cutter head setting angle and then reposition the gear centrally.

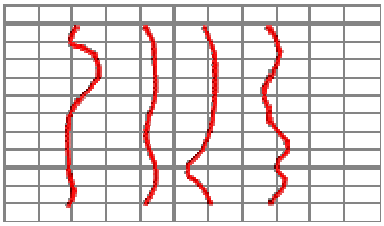
83. CUTTER GROUND WITH INCORRECT AMOUNT OF HOLLOW IN THE LEAD
Check the cutter re-sharpening to ensure that the profile produced is within the specification required. Be wary of any modifications to the profile of the cutter during a production run is not made due to inconsistencies of the component material or any other outside influences.

84. CUTTER IS GROUND WITH A CROWN IN THE LEAD
If crowning is not intentional, it may be due to inaccuracies in the resharpening machine, problems in the dresser or incorrect grade of grinding wheel.

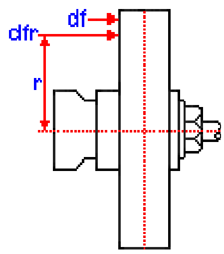
85. TABLE ANGLE SET IN THE WRONG QUADRANT FOR DIAGONAL SHAVING – *See* *Appendix 2*
The incorrect direction of rotation to direction of feed/traverse can affect quality and tool life.

4.2. Profile

4.2.1. Basic Form



86. CUTTER IS NOT MOUNTED SQUARE ON THE CUTTER ARBOR



Due to a shaving cutters large diameter, the datum face runout is of utmost importance. Failure to ensure the runout is within specification will cause profile errors. To calculate the amount of allowable runout for the diameter of cutter, use the following formula:

dfr = 0.0001" × r (0.0025mm × r)

Whereas:

dfr = datum face runout (maximum allowable runout at a given diameter).
df = datum face (reference face).
r = radius (radius at which the dial indicator is referencing).

Example:

r = 7"
dfr = 0.0001" × 7" = 0.0007"

Maximum allowable runout of shaving cutter reference face = 0.0007" measured at a radius of 7" (14" diameter).

87. INCORRECT FORM ON THE SHAVING CUTTER

Graph the cutter after resharpening to ensure it comes within specification.

88. WORN BEARINGS IN THE CUTTER HEAD

A maintenance schedule will help in this area.

89. WRONG PARAMETERS IN SET-UP

The shaving cutter drives a free turning component, consequently the right combination of speeds, feeds, traverse start and finish locations and upfeed cam should be set.

90. DULL SHAVING CUTTER

Shaving is a finishing process, the cutter should only remove a minimal amount of stock, typically 0.001" to 0.002" (0.025mm to 0.050mm). By increasing the profile checking frequency at about 75% of a cutters change frequency you will be able to catch wear due to inconsistencies of material stock.

91. VARIATION IN MATERIAL HARDNESS

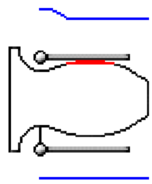
This is an area difficult to avoid, material hardness can be inherent or incurred during the roughing process due to work hardening.

92. INSUFFICIENT UNDERCUT IN PRE-SHAVED GEAR

A shaving cutter is not designed to cut in the root or fillet; pre-shaving with a protuberance cutter should be carried out prior to the shaving process.

93. USING A STRAIGHT SHANK STYLUS IN THE PROFILE TESTER FOR A GEAR WITH UNDERCUT

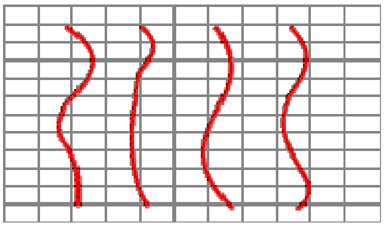
In the diagram right, the top probe is a straight shank with too small a ball diameter, this cannot reach the undercut due to interference with the tooth flank. The Bottom probe is cranked and can follow the undercut without any interference.



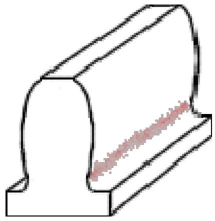
94. INSPECTION EQUIPMENT OUT OF CALIBRATION

A strict calibration schedule is important if consistency is to be maintained.

4.2.2. Irregularity



95. ADDENDUM OF THE CUTTER TEETH IS TOO LONG
An overlong cutter addendum will create an undercut at the base of the tooth. This is not desirable in a shaving cutter, as it will also create uneven cutting and thrust.



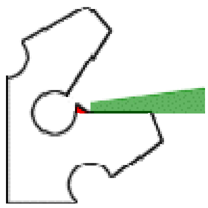
96. WORN BEARINGS IN THE CUTTER HEAD
A maintenance schedule will help reduce this problem.

97. TOO MANY IDLE PASSES BY THE SHAVING MACHINE
This not only accelerates the decline of tool life but the idle passes act similar to **spark-out** in a grinding wheel and remove additional stock in irregular areas.

98. PRE-SHAVED GEAR WAS UNDERSIZE
Consistency of stock removal is very important. Ensure the roughing process is producing consistent results and quality monitored as intently as the finishing process. Thinking that the shaving process will cure all ills is FICTION.

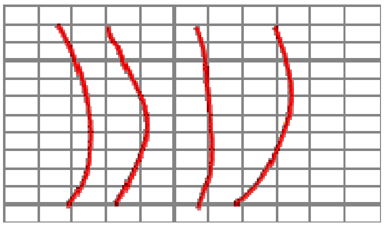
99. EXCESSIVE OR INSUFFICIENT HOLLOW IN THE TOOTH PROFILE OF THE SHAVING CUTTER
The cutter should be graphed after resharpening to ensure the profile is within specification.

100. CUTTER TEETH NOT GROUND ALL THE WAY DOWN TO THE CLEARANCE HOLES
These holes allow the grinding wheel to produce a full form.



101. EXCESSIVE IRREGULARITIES IN THE PRE-SHAVED GEAR
The pre-shave process must produce consistent quality; shaving will not remove all inconsistencies.

4.2.3. Variation



102. RUNOUT IN PD OF THE SEMI-FINISHED GEAR

The quality of the pre-shave gear is very important, as shaving will not remove all inconsistencies. Poor quality pre-shaved gears will produce poor quality shaved gears. Ensure the roughing process is producing consistent results and quality monitored as intently as the finishing process.

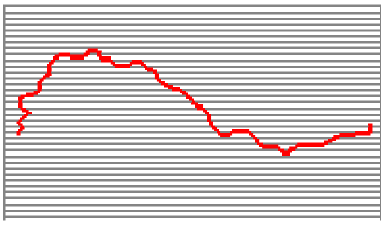
103. GEAR FACES NOT SQUARE WITH THE BORE

Identify the datum face and use throughout all processes including inspection. Be wary that parallelism may be within specification but by shaving two components at the same time you will get a tolerance build up.

> *Example:* if the tolerance is 0.002" and two components are each 0.0015". When put together to cut two at a time, one could be 0.003".

Tolerances should be reviewed if multiple parts are to be cut at any stage of manufacture.

4.3. Runout



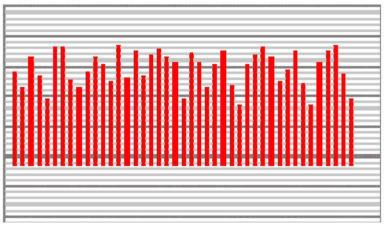
104. MISMATCH BETWEEN THE BORE OF THE GEAR AND THE OD OF THE CHECKING ARBOR
This may be due to wear in the checking arbor or inconsistencies in the component bore diameter. If the bore diameter tolerance cannot be tightened perhaps an adjustable mandrel would solve the problem.

105. EXTREME RUNOUT OF THE PRE-SHAVED GEAR
The shaving cutter drives a free running component; any runout discrepancy in the pre-shaved gear will produce a variation in tooth thickness and material removal resulting in uneven cutting pressures and ultimately cutter deflection.

106. RUNOUT GROUND IN THE SHAVING CUTTER
The cutter should be inspected after resharpening to ensure consistent quality.

107. ECCENTRIC CENTRES IN CHECKING ARBOR
A calibration procedure and schedule should be in force to ensure that all inspection equipment meets the required quality and standard.

4.4. Tooth Spacing



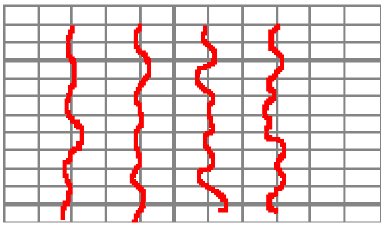
108. CUTTER GROUND ON A MACHINE WITH A WORN INDEX PLATE

On some older cutter sharpening machines, the index plate may require cleaning on the registration faces due to a build-up of contaminants.

109. PITCHING ERROR IN THE PRE-SHAVED GEAR

The quality of the pre-shave gear is of utmost importance if quality gears are to be produced at the shaving stage.

4.5. Tooth Surface Finish



110. FEED PER REVOLUTION OF THE CUTTER IS TOO HIGH
There is no direct drive between the cutter and component, consequently if the feed is too high it can push off creating imperfections in the surface finish.

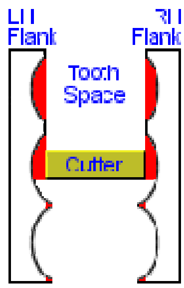
111. CUTTER ROTATING IN THE SAME DIRECTION AS THE TABLE TRAVEL - *See Appendix 2*.
The incorrect direction of rotation to direction of feed/traverse can affect quality and tool life.

112. UPFEED CAM AND/OR STROKES ARE NOT COMPATIBLE FOR THE FINISH REQUIREMENT
This governs the amount of feed increments including free passes; the setting is dependant on material stock and rigidity of setup.

113. SWARF LODGED IN THE SERRATIONS OF THE CUTTER
Insufficient or misdirected coolant flow will not wash out the swarf, ensure a good flow.

114. DAMAGED CUTTER TEETH
Damage to the cutter occurs most frequently when raising the table to set the backlash between cutter and component, also by the incorrect setting of the table stroke length. Damaged cutter teeth will leave imperfections in the component tooth surface.

115. FEED MARKS OF PRE-SHAVED GEAR ARE DEEPER THAN AMOUNT OF SHAVING STOCK
Result of poor quality hobbing, a specification for scallop depth at the hobbing process can often help with this problem.



116. BUILT-UP EDGE (CHIP WELDING) OF THE CUTTER TEETH

Often occurs with soft material, also the result of poor coolant flow or misdirected coolant flow. There are some good coolants being developed that aid cutting, tool wear and surface finish, consult your supplier.

117. IMPROPER CHEMISTRY IN THE CUTTING FLUID FOR THE WORK MATERIAL

Varying materials, including steels, alloys and plastics all benefit from different coolants and additives. Improvements in this technology is changing rapidly, consult your supplier for the correct specification.

118. EXCESSIVE SOFTNESS OF THE WORK MATERIAL

A soft material prevents a crisp chip formation and tearing of the component tooth surface, it will also contribute to chip build-up on the cutter teeth. Ensure a good coolant flow and consider coolant additives.

5. Summary

The Majority of Errors Found In The Manufacture of Gears Can Be Summarised Into The Following Categories: -

As we have seen, the causes of errors in gears are many.

Often the same cause can have different effects if the setup is different.

A number of different causes together can also greatly change the effect and its appearance.

This can make problem solving even more difficult.

But - it is often the commonest bugs that trip us up.

I use the adage:

**"If it moves, it could cause a problem.
If it doesn't move, it's still under suspicion".**

As a summary, and to help initial problem solving, we can break everything down into a few basic rules.

5.1.

THE GEAR BLANK IS NOT MACHINED WITHIN TOLERANCE

MIS-LOADING

SWARF

NICKS AND BURRS

DATUM FACE

TOLERANCE BUILD-UP

THESE ARE JUST A FEW THINGS
THAT CAN INFLUENCE COMPONENT ACCURACY.

5.2.

THE GEAR CUTTING/SHAVING MACHINE IS IN NEED OF REPAIR

A REGULAR CHECK OF OIL LEVELS WILL REDUCE WEAR

CLEANLINESS WILL STOP INGRESS OF SWARF INTO AREAS WHERE DAMAGE CAN OCCUR (AND PROMOTE AN ATTITUDE OF PRIDE)

USE CORRECT SIZE SPANNERS TO LESSEN DAMAGE IN AREAS OF ALIGNMENT.

THESE ARE ONLY A FEW BASIC BUT VERY IMPORTANT CARE POINTS THAT ARE OFTEN FORGOTTEN BUT WILL HELP PROMOTE A HEALTHY ATTITUDE AND MAINTAIN AN ACCURATE MACHINE.

THE MACHINE'S HANDBOOK WILL OFTEN CONTAIN MORE IN-DEPTH CARE POINTS SPECIFIC TO YOUR MACHINE AS WELL AS A FULL MAINTENANCE SCHEDULE.
WELL WORTH A READ.

5.3.

Something's Loose

Machine downtime is a constant concern.

When this is for a machine setup or tool change the pressure mounts on the person doing the setting. It is then, under this pressure, that a nut is missed from being tightened fully.

Work through your set-up in a methodical manner.

When finished, take 2 minutes to quickly check each nut and bolt for tightness.

These 2 minutes may save you hours of re-working components.

5.4.

THE COMPONENT, CUTTER OR FIXTURE IS NOT PROPERLY ALIGNED

A TRUE RUNNING COMPONENT ON AN ACCURATELY SET FIXTURE BEING GEARCUT BY A TRUE RUNNING CUTTER CANNOT FAIL TO PRODUCE A QUALITY PART. ANY MIS-ALIGNMENTS BETWEEN THESE WILL PRODUCE ERRORS AND CAN TRANSFER PROBLEMS TO OTHER AREAS.

CHECK HOB RUNOUT AFTER EACH CUTTER CHANGE.

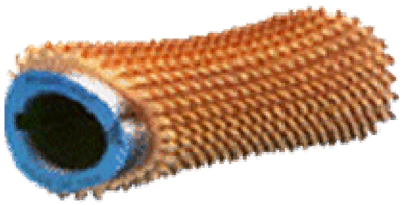
ARRANGE A MAINTENANCE SCHEDULE FOR CHECKING THE RUNOUT OF THE FIXTURE, ONCE PER WEEK OR SOONER.

IF YOU HAVE TO RUB THE LOCATING MANDREL WITH ABRASIVE MATERIAL BECAUSE THE COMPONENT IS TIGHT – IT IS PROBABLY NOT THE MANDREL BUT THE COMPONENT BORE THAT IS WRONG. THIS TYPE OF ACTION WILL ALTER THE LOCATION OF SUBSEQUENT, CORRECTLY MACHINED COMPONENTS.

ENSURE THE TOLERANCE BETWEEN THE BORE OF THE COMPONENT AND THE LOCATING MANDREL ARE COMPATIBLE FOR ACCURATE LOCATION OF THE COMPONENT.

5.5.

THE TOOL IS OUT OF TOLERANCE



YOUR TOOLING MANUFACTURER GOES TO GREAT LENGTHS TO PRODUCE TOOLS TO EXACTING STANDARDS.

CARE IN THE HANDLING

CARE IN THE STORAGE

CARE WHEN REGRINDING

WILL ALL HELP MAINTAIN THIS HIGH STANDARD

5.6.

Hammer Mechanics Produce Worn Equipment And Poor Quality

To maintain your machine in a condition that will produce quality components, long term, it has to be treated with respect.

Over-tightening, lack of cleanliness and ill-treatment are the most common factors that reduce your machine's life expectancy.

If a removable part is proving difficult to move, a hammer may well hurry things along this time, but it is only delaying the fact that something is wrong and should be fixed. It may have just been a bit of swarf (cleanliness) but your hammer has now added burrs and possibly distortion.

The old adage **The Bigger The Problem, The Bigger The Hammer** has no place in gearcutting if you want to produce good quality, long term.

Notes:

6.

APPENDICES

Notes:

6.1. Appendix 1 - Glossary of Terms

Variation – Follows a pattern

Irregularity – Does not follow a pattern

Radial – In the same plane as the rotation of the gear

Axial – in a direction along the axis of the gear

Lack of Human Perfection – Someone made a mistake. .. Oop's!

Lead Gears – Gears arranged on the machine to produce the helix angle. Also called differential gears

Ratio – the ratio of a set of gears can be calculated by: ~

$$\frac{DR1 \times DR2}{DN1 \times DN2} \quad \text{or} \quad \frac{A \times C}{B \times D}$$

Example: $$\frac{20}{40} \times \frac{30}{60} = (20 \times 30) \div (40 \times 60) = 0.25$$

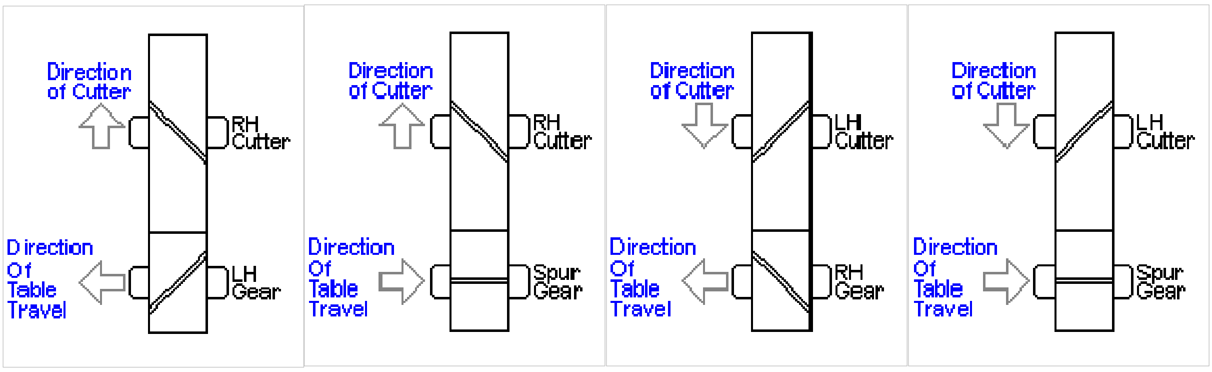
Actual Ratio – the ratio of the actual gears used on the machine

Theoretical Ratio – the ratio calculated as theoretically true.

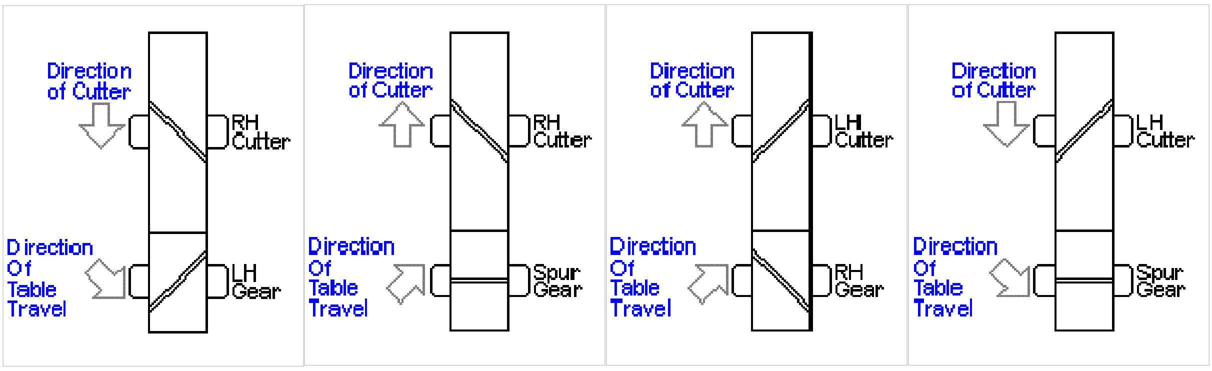
Index Gears – gears arranged on the machine to produce the number of teeth in the component gear

6.2. Appendix 2 - Shaving - Correct Direction For Cutter And Table

CONVENTIONAL SHAVING:



DIAGONAL SHAVING:



I hope this book has not only helped you to better understand Gear Graphs but also to gain knowledge of what can cause all those wondrous **Squiggly Lines**.

Along the way I hope I have contributed to improving your gear manufacturing processes.

This book is also available as a multimedia ebook with the diagrams animated. This allows you to see the **Cause and Effect** of the problem in a more entertaining and informative way.