CROWNED MOLDED PLASTICS GEARS

A NEW SOLUTION TO AN OLD PROBLEM

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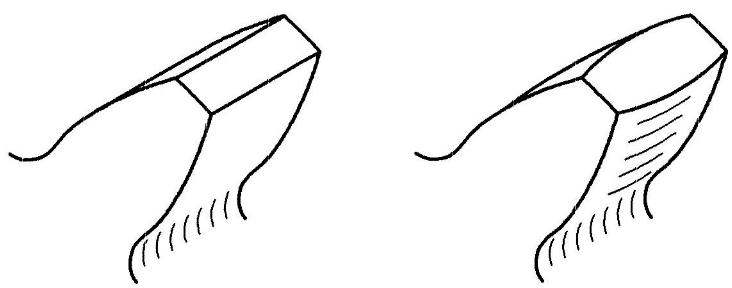
EDITOR'S NOTE: Many of the sketches, especially those depicting misalignments, are exaggerated to clarify a point.

INTRODUCTION

The old problem is the common condition of misaligned mating parallel-axis (spur and helical) gear tooth surfaces, as described below. The solution, new to molded plastic gears but old in machined gear practice, is the modification of gear flanks by making them full thickness at mid-face-width and tapering them to each edge. See figure (1). This modification, extending over the full height of the gear tooth, is referred to as *crowning*. The result is a *crowned* tooth or gear, not to be confused with other references in gear terminology.

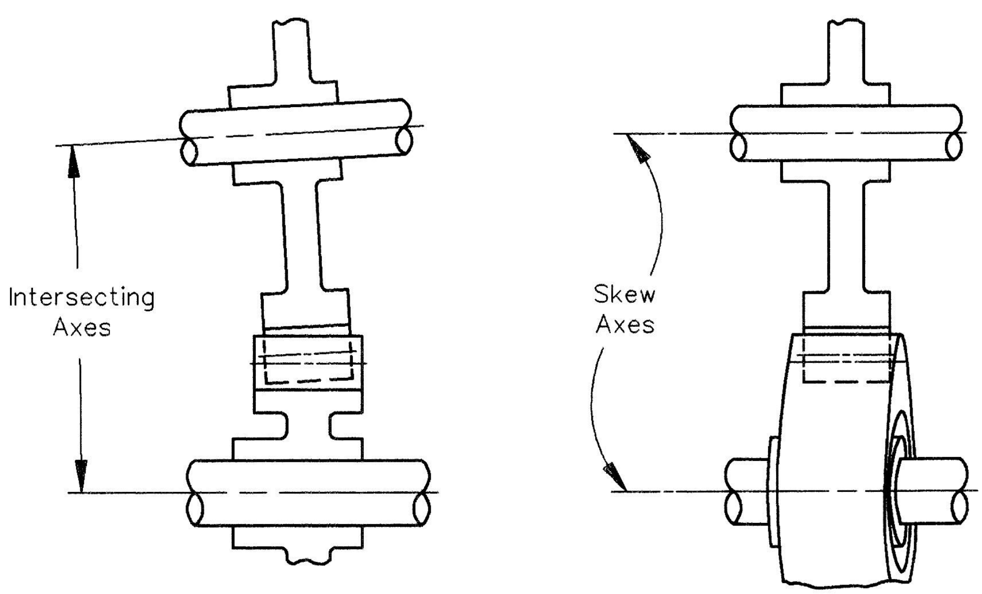
Fig (1)



MISALIGNMENT of GEAR TEETH

Instead of the ideally parallel gear rotation axes, the axes may be intersecting in the same plane, or skew in different planes, or a combination of both. See figure (2) for illustrations relating to spur gears.

Fig (2)

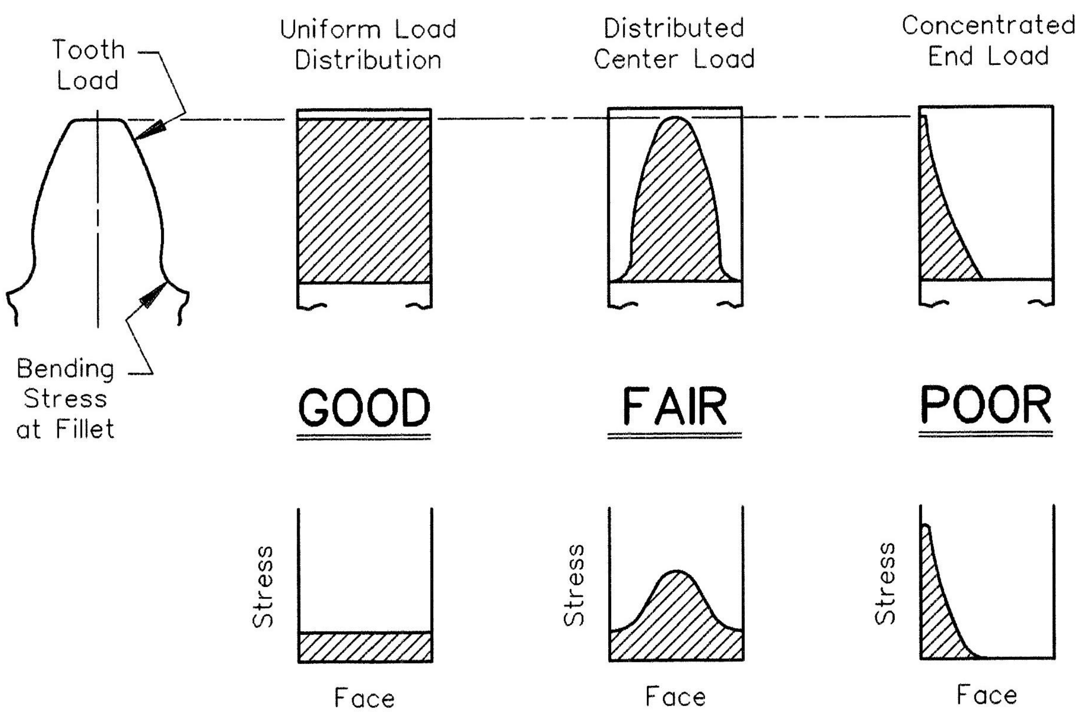


PROBLEMS CAUSED by MISALIGNMENT

The major problem associated with gear tooth misalignment is the concentration of contact to a narrow strip at one end of the gear face width. The load transmitted through this narrow width gains support from adjacent material on only one side of the contact area, resulting in high bending stresses. See figure (3). These high stresses may lead to the start of a crack which progresses across the face width until a major portion of the tooth breaks. Also, the concentrated area of contact may initiate rapid tooth surface wear with the wear detritus further accelerating surface failure.

In the case of helical gears, the localized area of contact due to misalignment reduces the helical continuity of contact. This reduction effectively eliminates the 'smoothing' action in motion transmission expected from helical gears.

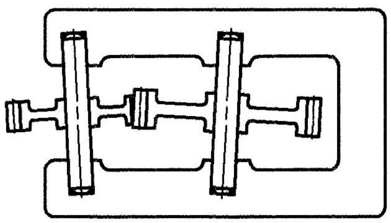
Fig (3)



SOURCES of MISALIGNMENT

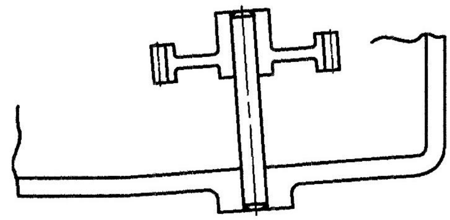
Molded plastic gears are commonly used with molded plastic housings, often of a fiber reinforced material. This process, with its often unpredictable distortions, makes it difficult to achieve and maintain a high degree of accuracy in gear alignment features. The same may be true in die-cast metal housings, even if less so with secondary machined bearing openings. All these housings are subject to further distortions under changes in temperature or the passage of time. See figures (4a) (4b).

Fig (4a)



Housing Misalignment

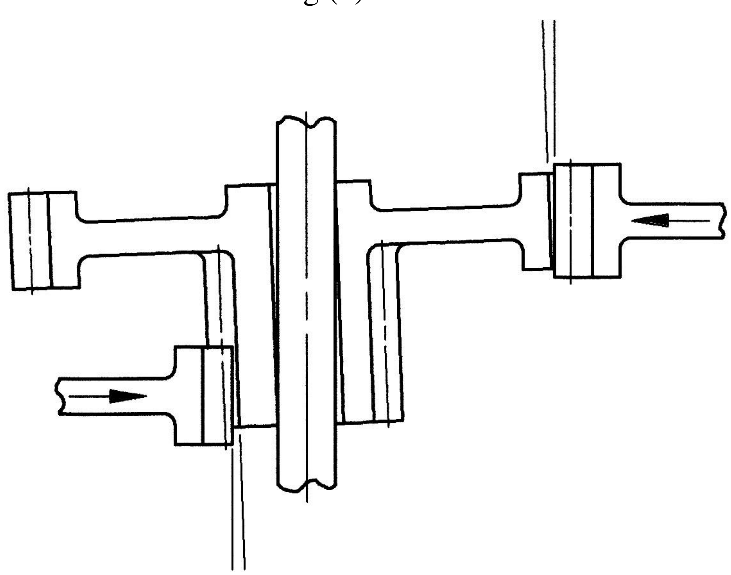
Fig (4b)



Housing Distortion

Also, molded plastic gears are most likely to be supported in sleeve bearings with relatively large clearances in contrast to the small clearances in ball bearings. If the journal and bearing diameters are produced by molding, with their sizes controlled by typical tolerances, the resulting clearances may permit significant misalignment. As shown in figure (5), the misalignment results from the combination of the clearance and the axially offset and opposing forces, such as those on compound gears. .

Fig (5)



Offset Tooth Loading on Driving & Driven Gears

In some plastic gear assemblies, the gears are supported by small diameter metal shafts, either fixed to the gear and rotating, or fixed to the housing and non-rotating. With either simple or cantilevered types of supports, there are further opportunities for gear misalignment. This results when there are forces large enough to deflect the shafts and when the gears are positioned on the high slope portion of the shaft deflection curve, as shown in figures (6a) and (6b). With slender molded plastic shafts in place of metal, the deflections may be even greater. Cantilevered support may also be accompanied by a compliant structure, as shown in figure (6c), where it is shown without accompanying shaft deflection.

Fig (6a)

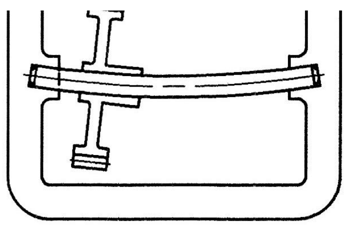


Fig (6b)

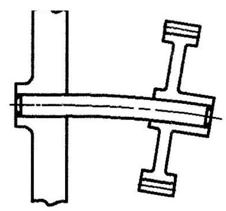
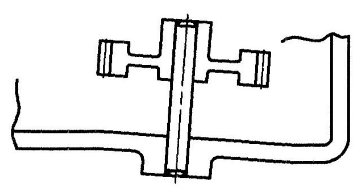
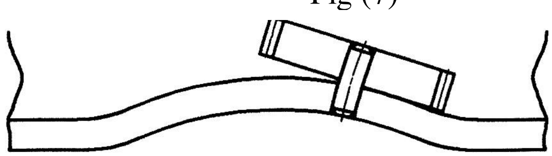


Fig (6c)



One type of gear assembly is particularly sensitive to misalignment due to deflections under load. The planet gear in planetary gear arrangements is often supported by a cantilevered shaft, which may be of limited diameter to reduce bearing friction losses. The web portion of the planet carrier, connecting the planet shafts, may be of reduced thickness to save space. The combined deflection of these features under load, pictured in figure (7) contributes to gear mesh misalignment.

Fig (7)



Then the gears themselves may have tapered faces, figure (8a), which will misalign and/or tapered bores which will allow movement under load. Distortion in the web creates wobble of the gear teeth to both sides of center, figure (8b).

Fig (8a)

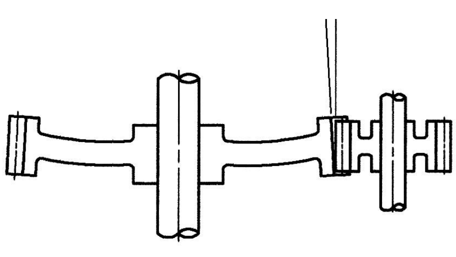
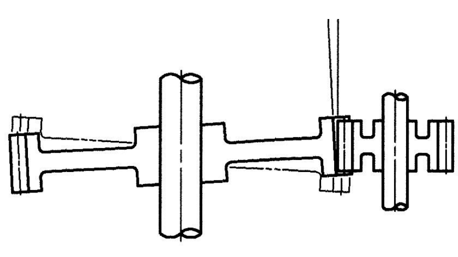


Fig (8b)



BENEFITS of CROWNING

The use of crowned gears can improve the adverse conditions imposed by tooth misalignment. Contact will be shifted away from the end of the tooth to some central location along the tooth flank. Instead of contact on a nearly sharp edge, over a narrow width at best, contact will take place along a gradually curved surface over a greater width. Support to the applied tooth load will come from this greater contact width and also from adjoining material on both sides of the contact center. Wear at the broader contact area will progress more slowly. If helical, more of the helical gear action will be maintained, often preserving the helical gear noise reduction. Refer back to figure (3).

There may be a further, if indirect, benefit of crowning. The application of crowning will permit a greater tolerance of misalignment in the product assembly. This relief may often be converted into manufacturing cost reduction.

CROWNING of MACHINED GEARS

There is a long standing practice of crowning machined steel gears. The modification of metal tooth surfaces is generally accomplished by secondary operations.

Crowned gears have been used in a great variety of gear transmissions, including automotive. There is a need even when the transmission housing is of rigid metal construction with accurately machined features for mounting ball bearings with negligible clearances. In applications associated with molded plastic gears, the need is greater.

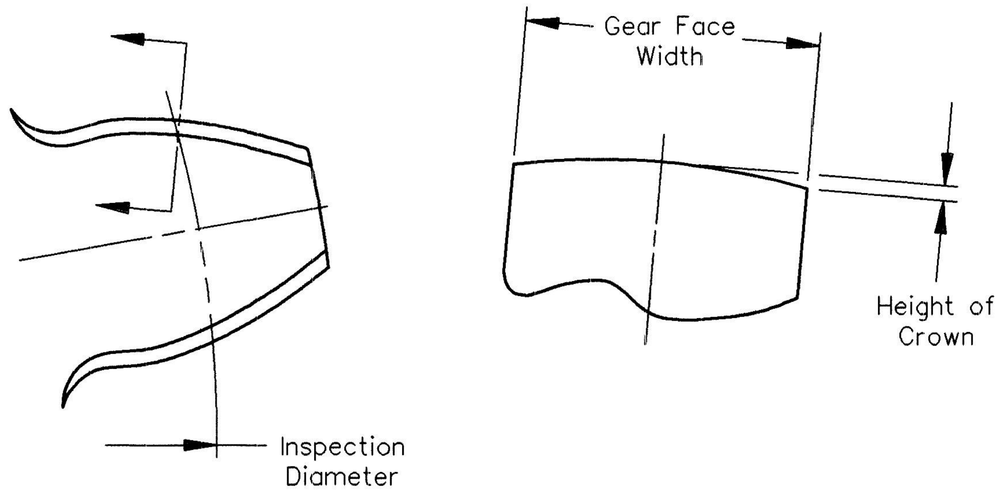
CROWNING of MOLDED PLASTICS GEARS

The recent introduction of crowned molded plastic gears has required significant development in new tooling and processing methods. The new tooling includes the construction of the mold cavity with varying cross-section, smallest at the ends and largest at the center of the face width The new processing covers the ejection of the molded gear while preserving the modified tooth surfaces. This requires the optimum control of the ejection timing so as to take advantage of the initial shrinkage and the limited elasticity of the still hot plastic material. This researched process is readily available for spur gears and some helical gears. Except for a moderate increase in the cost of tool construction, there is no significant increase in molded gear cost.

DESIGN of CROWNED GEARS

Crown is commonly specified by the height of the circular arc spanning the width of the gear tooth in a direction perpendicular to the tooth surface, see figure 9.

Fig (9)



A simple equation may be used to determine the height of crown needed:

$$h_C = \frac{2 F \alpha}{3}$$

where: h_C = height of the crown as a circular arc normal to the tooth surface, required to maintain contact in the central third of the face width, see figure 9

F = face width spanned by the crown

α = angle of misalignment, in radians

As an example, for shaft support misalignment of .005 inches over a length of 1.25 inches, giving a value to the angle, α, of $.005 \div 1.25 = .004$ radians. For a face width, F = .375 inches, the required height of crown, $h_C = 2 \times .375\ (.004) \div 3 = .0010$ inches

A tolerance, Tol(h_C), should be applied as an addition to the design value of crown height. A proposed tolerance may be calculated from the equation:

$$\mathrm{Tol}(h_C) = .0002 + (.20 \times h_C) \text{ inches}$$

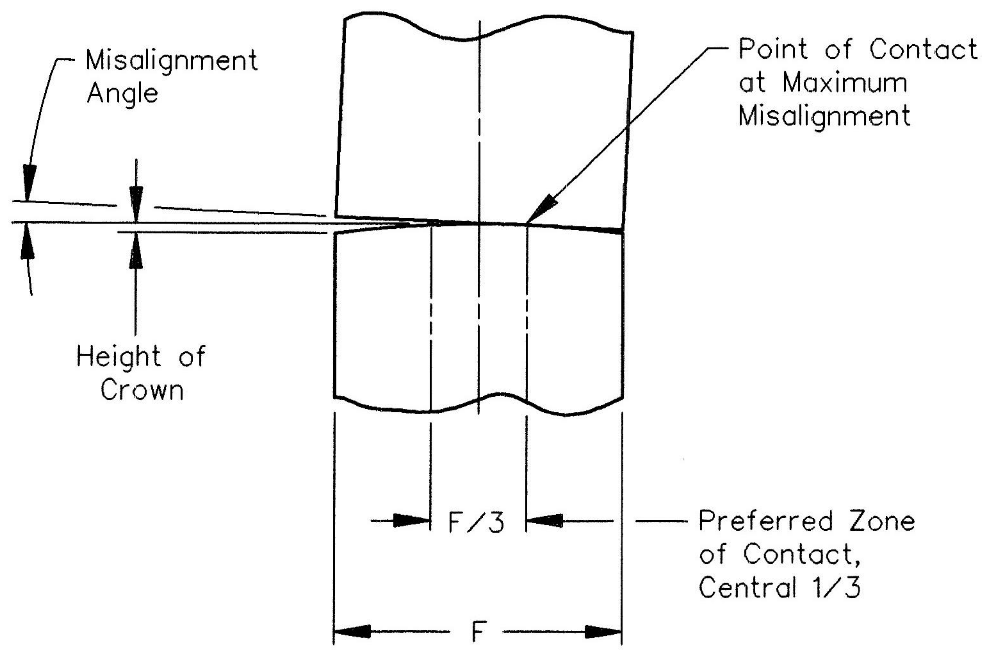
For the above example, the tolerance would be:

$$\mathrm{Tol}(h_C) = .0002 + (.20 \times .0010) = .0004 \text{ inches}$$

The full required crown is generally applied to only one of the two mating gears, preferably to the gear which will provide the greater shrinkage clearance to assist in the ejection of the molded part. If the two gears are from materials with similar shrink rates, this would be the larger gear. If the required crown height is too large to be accommodated in the molding of a single gear, it may be divided as needed between the two mating gears.

The preferred zone of contact is the central one third of the face width. See figure (10).

Fig (10)



SIZE and PITCH LIMITATIONS

If the gears have very narrow face widths, there is no significant benefit from adding crowning. A tentative lower limit on face width in inches is 2.5 divided by the diametral pitch (in millimeters, 2.5 times the module). There is no upper limit, with the larger face width most likely to require greater crowning.

As to gear diameter, there is again no upper limit. The lower limit is based on the shrink rate of the gear material and other factors which will influence the ease of molded part ejection. For higher shrinkage material such as un-reinforced acetal or nylon, one-half inch (12.7 mm) pitch diameter is a tentative lower limit. This lower limit is likely to be revised as experience is expanded.

The pitch (or module) of the gear has to be considered before specifying crowning. There is no upper limit on how coarse the pitch. When it comes to how fine the pitch, restrictions apply that relate to the methods of mold cavity processing and, in some cases, to the fillet design of the gear tooth. A tentative limit is the diametral pitch of 32 (or the module of .80). This limit, too, is likely to be revised with greater experience.

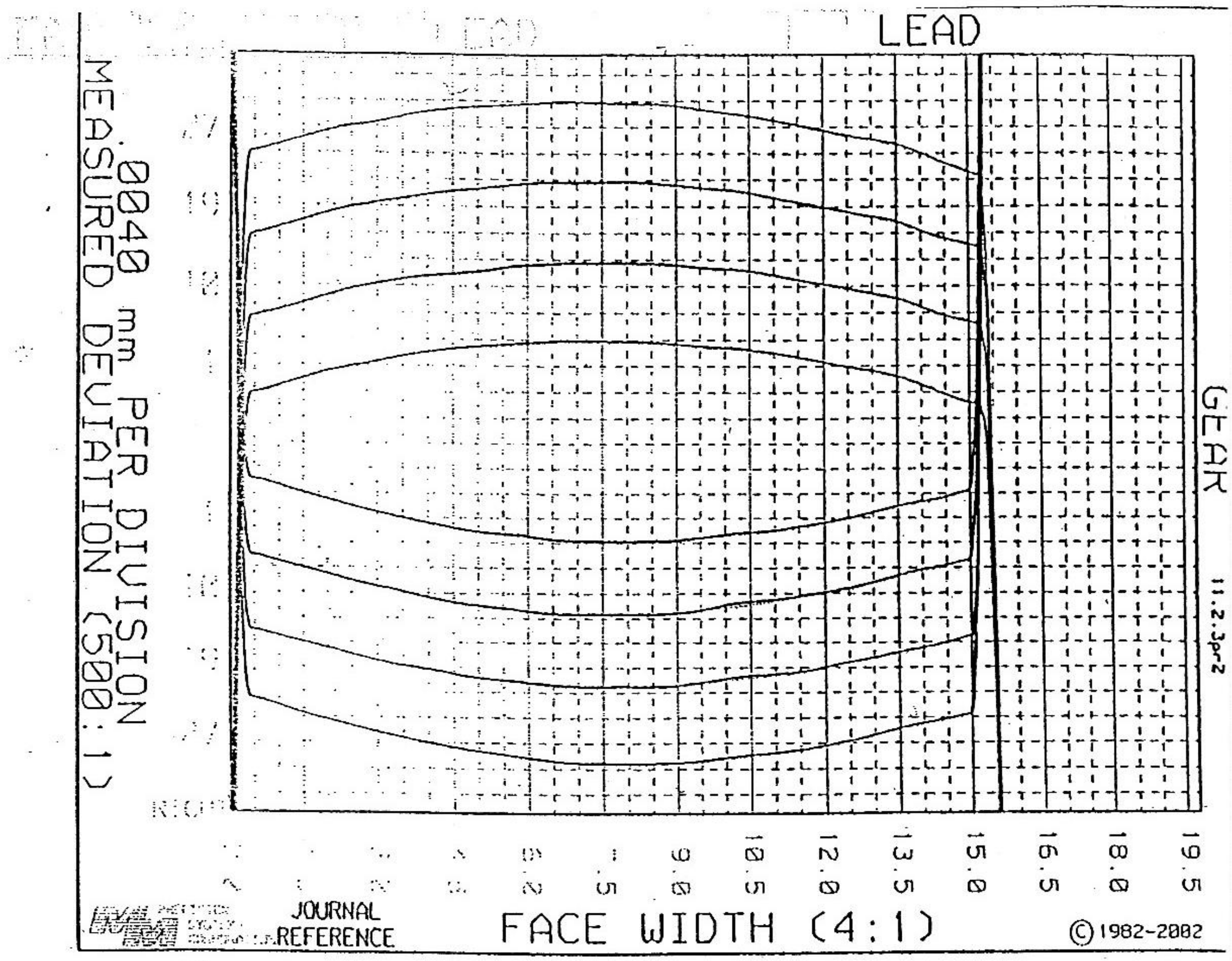
These limits are based on experience with spur gears. They may be applied to helical gears with helix angles up to, say, 30 degrees. However, other issues relating to tool processing and part ejection may, with further experience, introduce tighter limits.

CROWN INSPECTION

Inspection of the crown, for shape and height, is generally made on elemental gear inspection equipment, such as supplied by the M & M Company. The measuring probe follows the gear surface at the inspection diameter from one face to the other. On spur gears, its path is a straight line. On helical gears, the gear is rotated as specified by the gear design and the path of the probe relative to the rotating gear is a helix. This is typically applied to four equally, or nearly equally, spaced teeth.

The results of this inspection are in the form of magnified plots of the measured surfaces. The shape of the crown is apparent in each of these plots and the height may be read from the enlarged scale. In addition, the height values are typically supplied in printed form. See figures

Figure (11) represents measurements made on machined steel automotive gears. The printed values show crown heights of approximately .0003 inches (.007 mm).
Figure (12) represents measurements made on a plastics gear molded at ABA-PGT.
The values range from .0014 to .0017 inches, which handily met the original tolerance specification of .0015 +/- .0005 inches.



LEFT FLANK

TOOTH	1	10	19	27	TOL	MEAN
TOTAL ERROR Fß	.0016	.0016	.0022	.0029	.0090	
ANGLE ERROR fHß	-.0015	-.0012	-.0021	-.0032	.0080	
FORM ERROR fßf	.0004	.0005	.0006	.0008	.0055	
CROWN ACTUAL Cba	.0064	.0066	.0068	.0070		.0067 mm = .0003

RIGHT FLANK

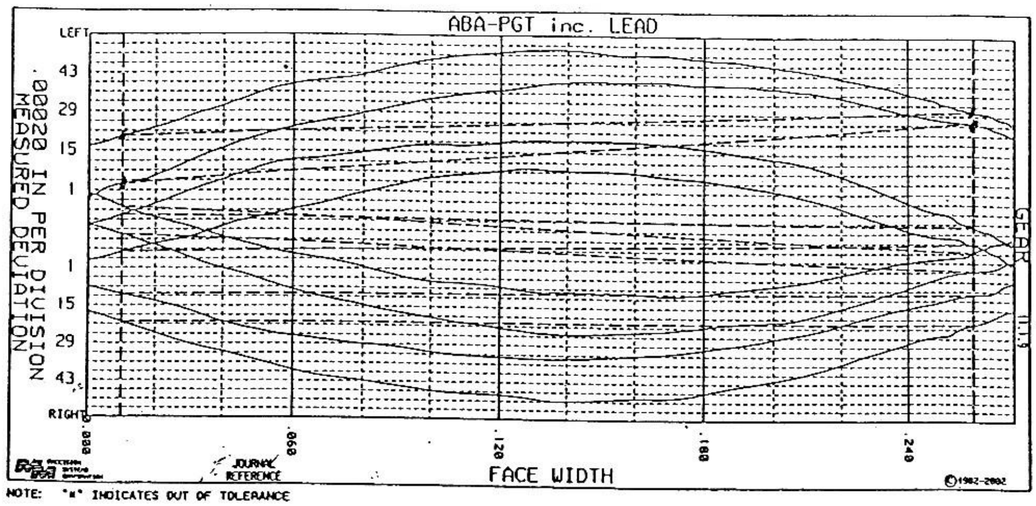
TOOTH	1	10	19	27	TOL	
TOTAL ERROR Fß	.0015	.0011	.0009	.0016	.0090	
ANGLE ERROR fHß	.0011	-.0000	.0005	.0017	.0080	
FORM ERROR fßf	.0007	.0009	.0009	.0005	.0055	
CROWN ACTUAL Cba	.0071	.0073	.0067	.0068		.0070 mm = .0003

Figure (11) Inspected crown on a machined steel automotive gear

OPERATOR : GLENN ELLIS
PART NAME : GEAR
INSPECTION NOTES :
.031 PROBE, .532 PIN, KO UP, .70 BLOCK GEAR FACE

DATE : 15 Sep 2003
TIME : 09:45

PART # : FP-01140 JR GEAR
SERIAL # : 2



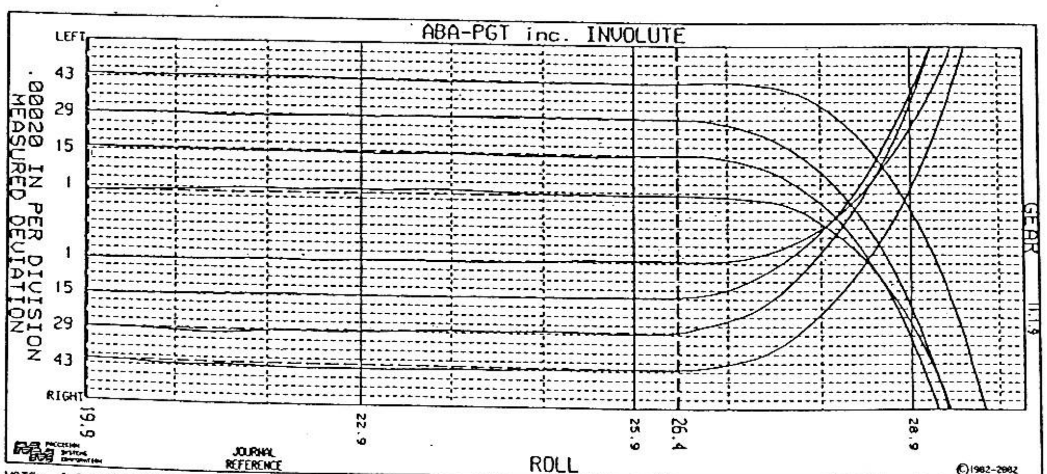
NOTE: "*" INDICATES OUT OF TOLERANCE

TOOTH	LEFT FLANK SLOPE	LEFT FLANK HOLLOW	LEFT FLANK CROWN
1	.00024	.00000	.00162
15	-.00016	.00000	.00163
29	.00133	.00000	.00141
43	.00060	.00000	.00152

TOOTH	RIGHT FLANK SLOPE	RIGHT FLANK HOLLOW	RIGHT FLANK CROWN
1	.00086	.00000	.00133
15	.00068	.00000	.00171
29	-.00008	.00000	.00138
43	-.00003	.00000	.00166

CONSTRUCTION LINE TYPE ANALYSIS

	LEFT FLANK	RIGHT FLANK
AVERAGE SLOPE	.00050	.00036
AVERAGE CROWN	.00155	.00152
MAXIMUM HOLLOW	.00000	.00000
MAX SLOPE VAR	.00149	.00094



NOTE: "*" INDICATES OUT OF TOLERANCE

TOOTH	LEFT FLANK SLOPE	LEFT FLANK HOLLOW	LEFT FLANK CROWN
1	.00004	.00000	.00011
15	-.00005	.00005	.00000
29	-.00003	.00004	.00003
43	-.00008	.00004	.00001

TOOTH	RIGHT FLANK SLOPE	RIGHT FLANK HOLLOW	RIGHT FLANK CROWN
1	-.00007	.00002	.00003
15	-.00006	.00004	.00002
29	-.00005	.00002	.00008
43	.00006	.00000	.00009

CONSTRUCTION LINE TYPE ANALYSIS

	LEFT FLANK	RIGHT FLANK
AVERAGE SLOPE	-.00003	-.00003
AVERAGE CROWN	.00004	.00005
MAXIMUM HOLLOW	.00005	.00004
MAX SLOPE VAR	.00012	.00014

Figure (12) Inspected crown on a plastics gear molded at ABA-PGT