Applying Elemental Gear Measurement to Processing of Molded Plastic Gears

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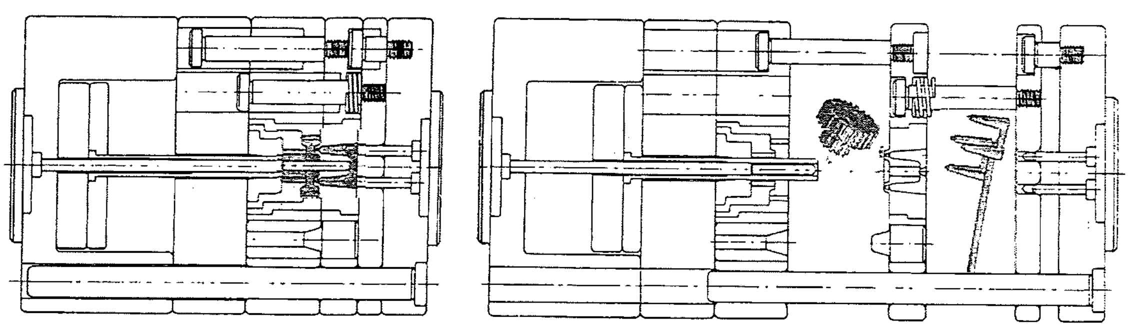
Elemental inspection of molded plastic gears has not been practiced until recent years. Its use has been limited to a few plastic molders specializing in gears, possibly because of the cost of the elemental inspection machine or the unfamiliarity with its benefits. They are not commonly used for everyday inspection of molded plastic gears. They are, however, used very successfully as a diagnostic tool during the advanced development of the mold and molding process. This paper will present examples of such use.

The gear molding process includes the molding machine and the mold. The plastic material, in granular form, is loaded into the machine where the plastic is heated and melted. At the start of the molding cycle, after the mold is closed, the molten plastic is injected into the mold at a controlled temperature, flow rate and pressure. In the mold, the molten plastic flows through a runner system and enters each gear cavity through a gating system. After sufficient cooling and solidification, the mold is opened and the gears ejected with the help of knockout (ejector) pins. After the ejected gear is further cooled and the plastic adequately conditioned, it is ready for inspection. (Fig. 1)



Close **Open**

Figure 1

All parts of this process determine the accuracy of the molded gear, starting with the choice of the plastic material and whether it is filled or unfilled. The influences continue with the design of the gear, including provision for gate location and shape, features, such as ribs and posts,

out-of-round bore, and wall thickness size, can introduce varying cross sections and lead to varying degrees of mold shrinkage throughout the gear. Ideally, design change can be made to the gear to make it more "molder friendly". Uniform wall thickness is the best. With this there is a better chance of similar shrinkage through out the part. Ribs may be required for structural reasons but they cause irregular wall sections leading to varying shrinkage. Posts and holes will also disrupt the shrinkage. Some of these features also alter the flow of material. This is particularly a problem with filled materials. When two material melt flows come together the fiber orientation will change altering the shrinkage. This is known as a knit (weld) line. All of these will have an influence on the final shape which will have to be compensated for to mold an expectable gear. Proper and experienced molding can further help improve the part outcome but in some cases actual steel rework is required.

The features in the design of the part carry over to the design of the mold. The first items selected might be the location and design of the gates and knockouts. The gear design then has a shrinkage allowance added to the gear tooth form to arrive at the cavity design. In many cases, with a simple part and with an unfilled plastic material, this cavity design will lead to a gear made to print without further study. In many other cases, further evaluation, including the elemental inspection, is required to upgrade the quality of the gear.

Double-flank gear checkers are typically used on the initial inspection, to compare gear accuracy to part specifications. This will indicate whether the molded gear is acceptable without further effort. If not, the inspection will often suggest the condition leading to part rejection.

In the double-flank check, the plastic gear is rolled together in close mesh with a master gear, with a spring or its equivalent used to maintain the close mesh condition. The recorded center distance will typically vary over the full rotation of the plastic gear. This plotted record compares the gear accuracy to the gear part specifications pointing out any excessive deviations. There are times when a solution can be found right away. Other times are when the diagnostic service of the elemental inspection is needed. The double flank inspection will continue to be used for in-process inspection where the elemental inspection is used for initial evaluation and trouble shooting.

It is common practice to make a full set of the elemental measurements: profile, lead, index, and derived tooth thickness. The printouts of the inspection results include both a plot and numerical values. The plot supplies an immediate understanding of the gear geometry and helps to identify the potential trouble spots. The numerical data will be used in deciding which of these trouble spots require process changes or tool changes and what should be the size of those changes. (Fig. 2)

In some cases the error is symmetrical around the whole part. This may be caused by a simple missed shrinkage. This is the most common and generally easy to correct. Once the error is identified by use of the elemental inspection a new cavity can be built with a modified shape so that the next parts molded will shrink within specifications.

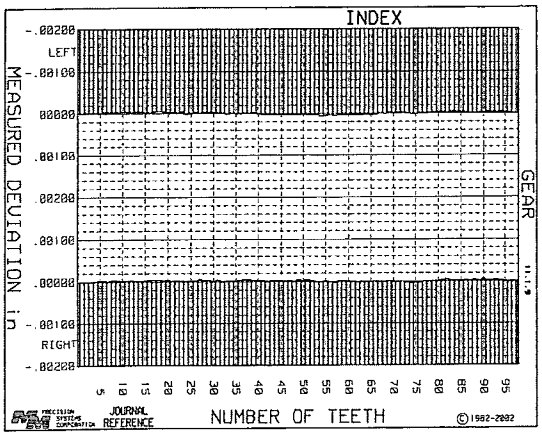
The error may be in the profile or the lead. In some cases it may be both. Typically four teeth are evaluated for these features. More or less teeth can be checked as needed. When checking the profile and lead the outputs are slope, crown and hollow. Limits are set for the range that you want evaluated. The slope is the amount of change within the set limits. The crown is the maximum measure of any convex condition along the profile. Hollow is the maximum measure of any concave condition along the profile.

The profile is checked from the form diameter out to the tip. There are times that the tooth profile varies as you go around the gear. This is usually caused by a filled material or an odd feature on the part. If this occurs the mold cavity must have varying tooth profiles to compensate for the error. Another profile problem may be caused by taper. This is when the profile is different from one end to the other. It is good practice to check the profile in more then one location. Additional compensation in the mold cavity will be needed for this problem.

The lead is checked in a similar way to the profile. This should be checked whether it is a spur or helical gear. When checked on a spur gear a tooth taper can be detected. On a helical gear the lead can be verified and also any tooth taper can be seen. As with the profile, the lead can vary around the gear because of different shrinkages due to a filled material or odd features.

The index and tooth thickness is measured at the same time. All of the teeth are checked around the gear for this measurement. Based on this

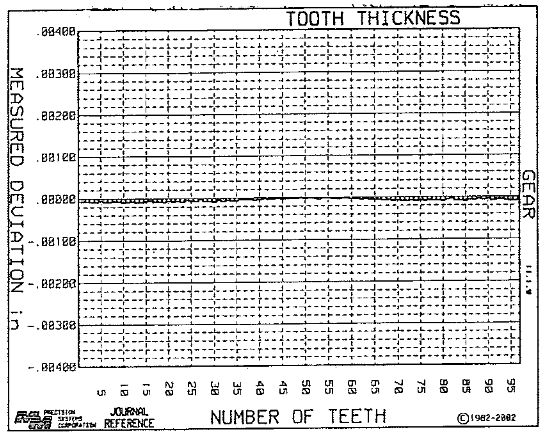
measurement the index, pitch and spacing is calculated. Also from this measurement the computer will calculate the average tooth thickness, the tooth thickness variation and the runout. Once again the index and tooth thickness may vary due to the material shrinkage.



LEFT FLANK	
TOTAL INDEX VARIATION	.00011 in
WORST PITCH VARIATION	.00005 in TEETH 23 AND 24
WORST SPACING VARIATION	.00006 in TEETH 22, 23 AND 24

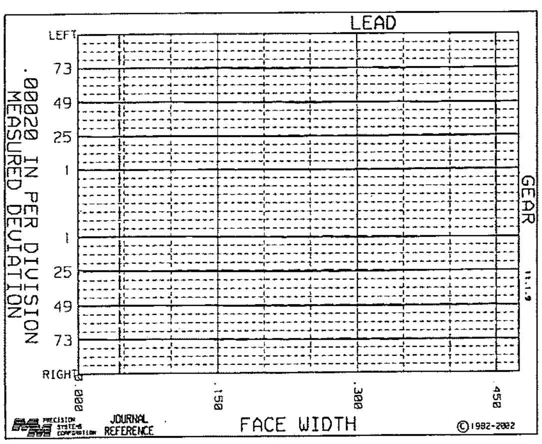
RIGHT FLANK	
TOTAL INDEX VARIATION	.00007 in
WORST PITCH VARIATION	.00003 in TEETH 35 AND 36
WORST SPACING VARIATION	.00006 in TEETH 30, 31 AND 32

ANALYZED RUNOUT .00004 in AT 232.0°



TOTAL THICKNESS VARIATION	.00010 in
AVERAGE TOOTH THICKNESS	.03284 in

ANALYZED RUNOUT .00004 in AT 232.0°

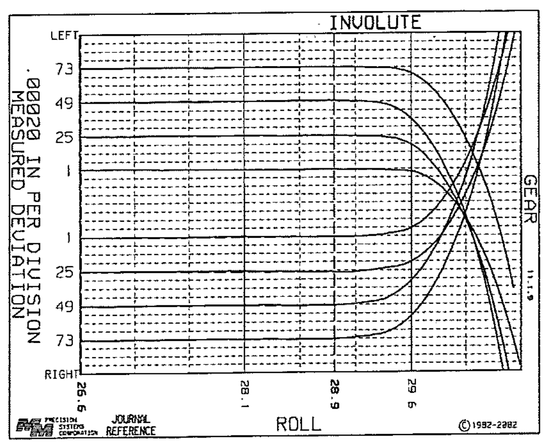


NOTE: "*" INDICATES OUT OF TOLERANCE

LEFT FLANK				RIGHT FLANK			
TOOTH	SLOPE	HOLLOW	CROWN	TOOTH	SLOPE	HOLLOW	CROWN
1	.00000	.00001	.00001	1	.00003	.00001	.00002
25	.00001	.00002	.00000	25	.00002	.00000	.00003
49	-.00002	.00002	.00001	49	.00001	.00000	.00002
73	-.00001	.00002	.00001	73	.00001	.00000	.00002

CONSTRUCTION LINE TYPE ANALYSIS

	LEFT FLANK	RIGHT FLANK
AVERAGE SLOPE	.00000	.00002
AVERAGE CROWN	.00001	.00002
MAXIMUM HOLLOW	.00002	.00001
MAX SLOPE VAR	.00002	.00002



NOTE: "*" INDICATES OUT OF TOLERANCE

LEFT FLANK				RIGHT FLANK			
TOOTH	SLOPE	HOLLOW	CROWN	TOOTH	SLOPE	HOLLOW	CROWN
1	-.00002	.00001	.00001	1	.00000	.00002	.00000
25	-.00001	.00001	.00001	25	.00003	.00003	.00000
49	.00001	.00001	.00000	49	.00001	.00002	.00001
73	.00000	.00001	.00001	73	.00000	.00002	.00001

CONSTRUCTION LINE TYPE ANALYSIS

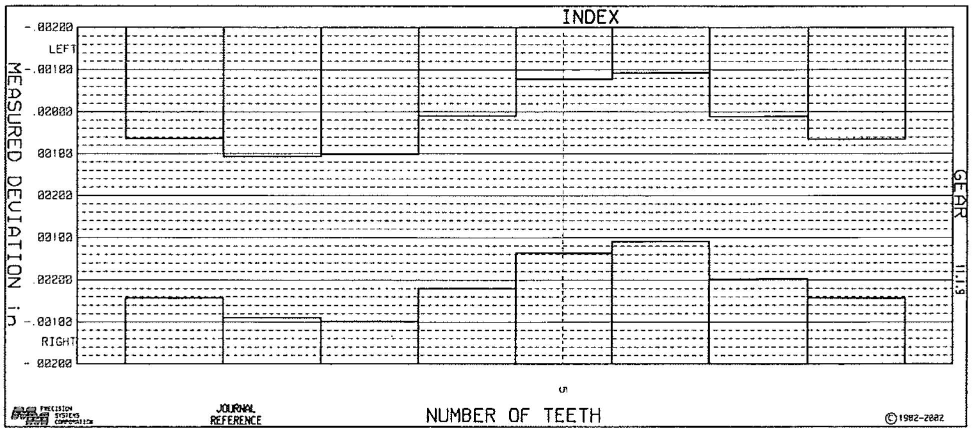
	LEFT FLANK	RIGHT FLANK
AVERAGE SLOPE	-.00001	.00001
AVERAGE CROWN	.00001	.00001
MAXIMUM HOLLOW	.00001	.00003
MAX SLOPE VAR	.00003	.00003

Figure 2

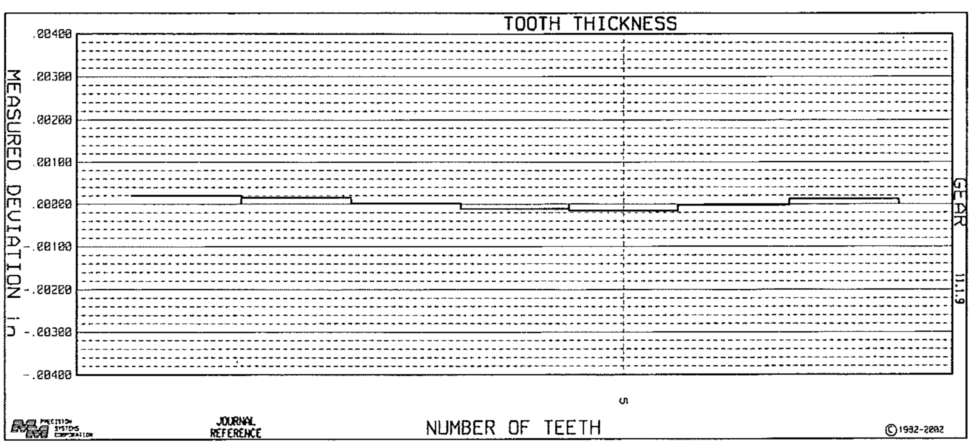
Example #1

This is a 7 tooth spur gear of 24 diametral pitch and 20 degree pressure angle. The material is an unfilled nylon, a high shrinkage material. The problem appeared to be caused by a "D" shaped central hole. The

double flank inspection chart revealed the resulting out of round condition. From the parts molded in the initial gear cavity design, elemental inspection showed very good profile and lead. The problem was revealed in the index measurement, see figure 3. The upper part of the index plot shows that the left flank had a total variation of .0020 with the right flank showing .0019. The lower part of the figure shows the tooth thickness values derived from these index measurements, with a variation of .0004. The results of the mold cavity change are shown in figure 4, with the index values reduced to .0005 and .0006

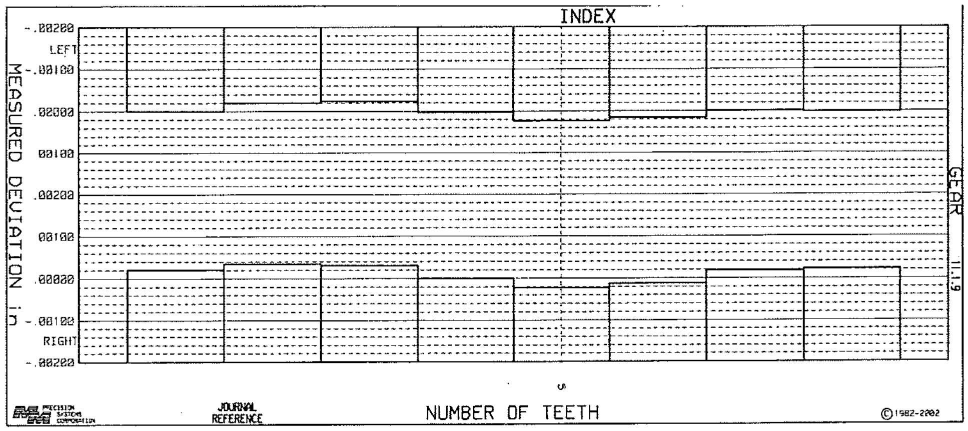


LEFT FLANK		
TOTAL INDEX VARIATION	.00199 in	
WORST PITCH VARIATION	.00103 in	TEETH 6 AND 7
WORST SPACING VARIATION	.00118 in	TEETH 5, 6 AND 7
RIGHT FLANK		
TOTAL INDEX VARIATION	.00189 in	
WORST PITCH VARIATION	-.00088 in	TEETH 6 AND 7
WORST SPACING VARIATION	.00116 in	TEETH 5, 6 AND 7
ANALYZED RUNOUT	.00183 in	AT 61.1°



TOTAL THICKNESS VARIATION	.00036 in	
AVERAGE TOOTH THICKNESS	.06391 in	
ANALYZED RUNOUT	.00183 in	AT 61.1°

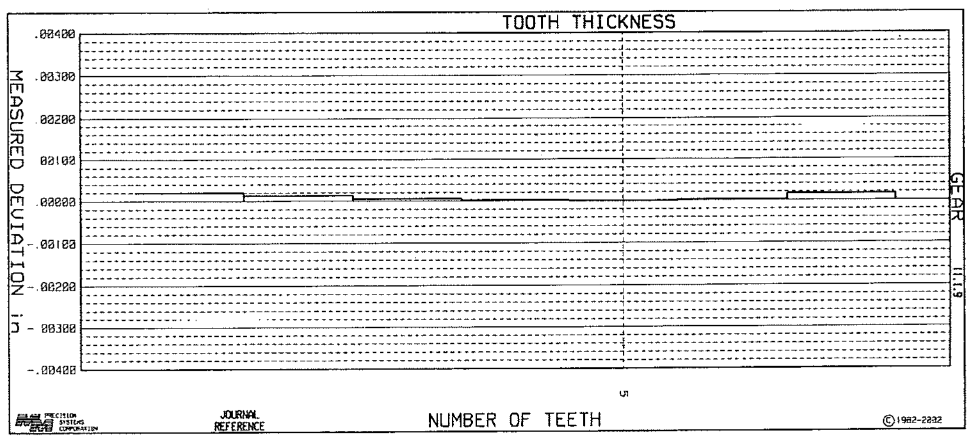
Figure 3
(Before rework)



LEFT FLANK
TOTAL INDEX VARIATION .00047 in
WORST PITCH VARIATION .00026 in TEETH 3 AND 4
WORST SPACING VARIATION .00030 in TEETH 2, 3 AND 4

RIGHT FLANK
TOTAL INDEX VARIATION .00057 in
WORST PITCH VARIATION -.00031 in TEETH 3 AND 4
WORST SPACING VARIATION .00032 in TEETH 4, 5 AND 6

ANALYZED RUNOUT .00045 in AT 250.3°

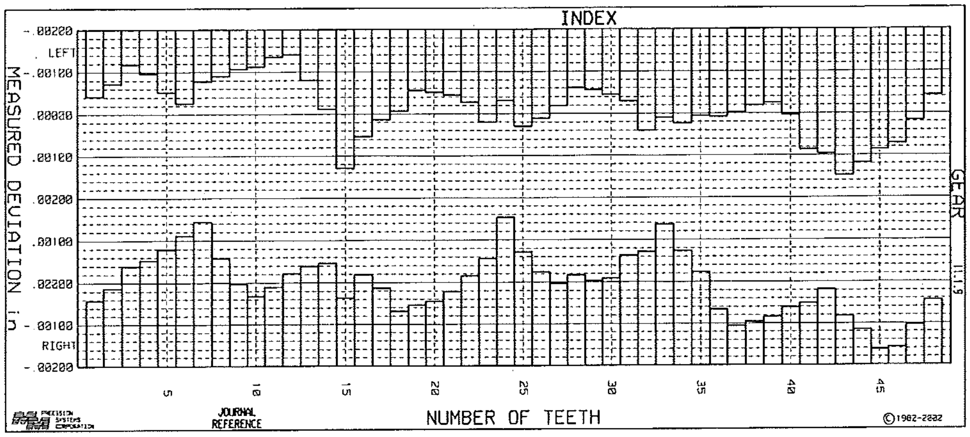


TOTAL THICKNESS VARIATION .00020 in
AVERAGE TOOTH THICKNESS .06434 in

ANALYZED RUNOUT .00045 in AT 250.3°

Figure 4
(After rework)

Example #2
This is a 47 tooth spur gear, with a module of 1 and a 20 degree pressure angle. The part was molded with five gates with knit lines leading to varying shrinkage around the gear. Figure 5 showed the results. The tooth thickness variation was .0029, but with a runout of only .0008. Figure 6 shows the results after modifications. The tooth thickness variation has been reduced to .0010 with the runout of .0007 even slightly smaller than before.



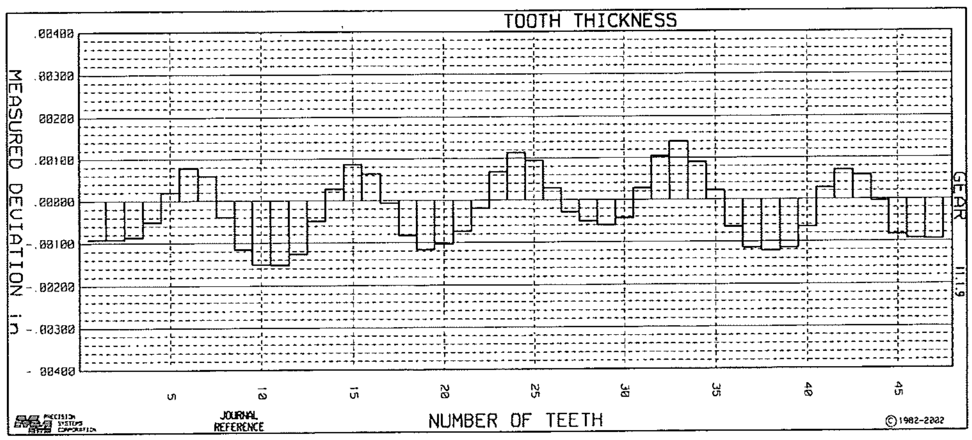
LEFT FLANK

TOTAL INDEX VARIATION	.00289 in	
WORST PITCH VARIATION	.00141 in	TEETH 14 AND 15
WORST SPACING VARIATION	.00219 in	TEETH 14, 15 AND 16

RIGHT FLANK

TOTAL INDEX VARIATION	.00316 in	
WORST PITCH VARIATION	.00097 in	TEETH 23 AND 24
WORST SPACING VARIATION	.00178 in	TEETH 23, 24 AND 25

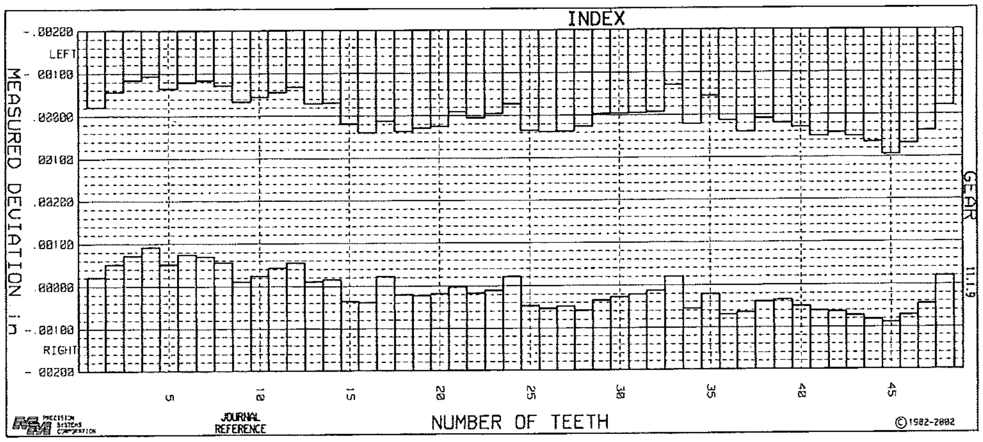
ANALYZED RUNOUT .00077 in AT 298.6°



TOTAL THICKNESS VARIATION	.00292 in
AVERAGE TOOTH THICKNESS	.04877 in

ANALYZED RUNOUT .00077 in AT 298.6°

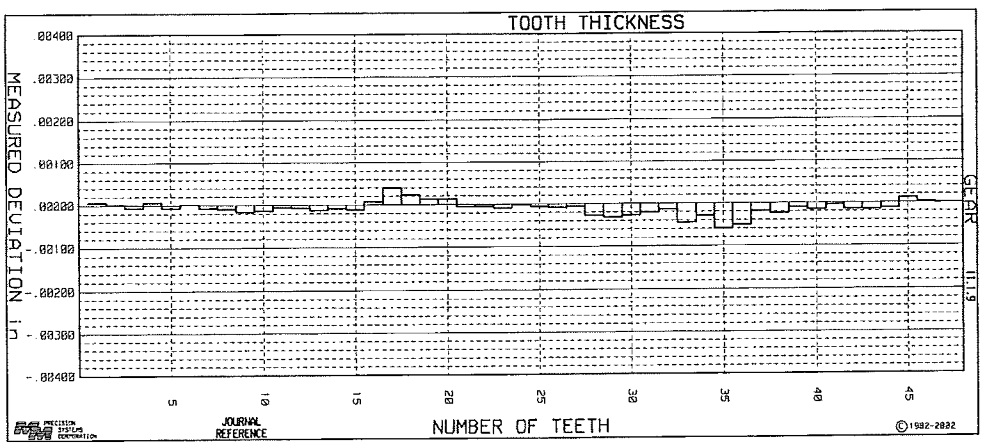
Figure 5
(Before rework)



LEFT FLANK
TOTAL INDEX VARIATION .00186 in
WORST PITCH VARIATION .00091 in TEETH 33 AND 34
WORST SPACING VARIATION .00157 in TEETH 33, 34 AND 35

RIGHT FLANK
TOTAL INDEX VARIATION .00181 in
WORST PITCH VARIATION -.00075 in TEETH 33 AND 34
WORST SPACING VARIATION .00110 in TEETH 33, 34 AND 35

ANALYZED RUNOUT .00068 in AT 248.5°

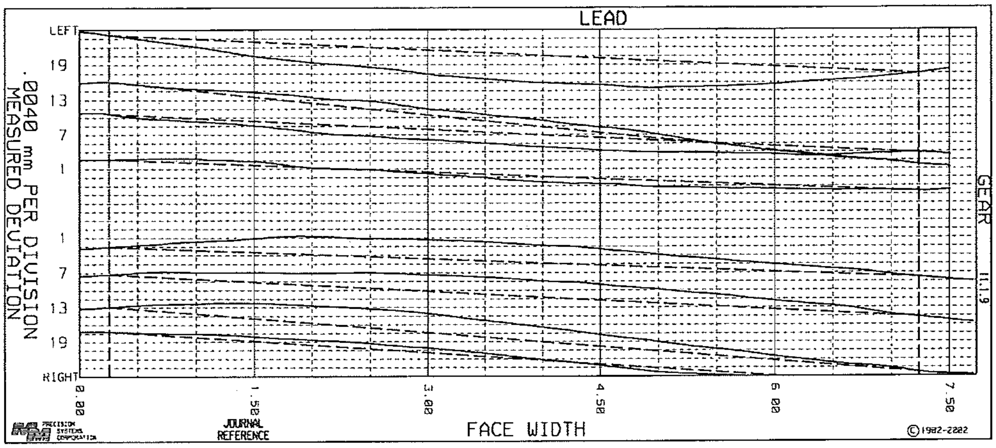


TOTAL THICKNESS VARIATION .00099 in
AVERAGE TOOTH THICKNESS .05077 in

ANALYZED RUNOUT .00068 in AT 248.5°

Figure 6
(After rework)

Example #3
This is a 24 tooth helical gear. It is a 24 diametral pitch and 9 degree helix angle. The upper portion of Figure 7 shows that the helix angle was close to 9.19 and the involute slope is high. Work to the cavity was done for both the lead and slope. After the cavity was altered the helix angle was improved to 9.02 and the involute was greatly improved (Fig. 8).

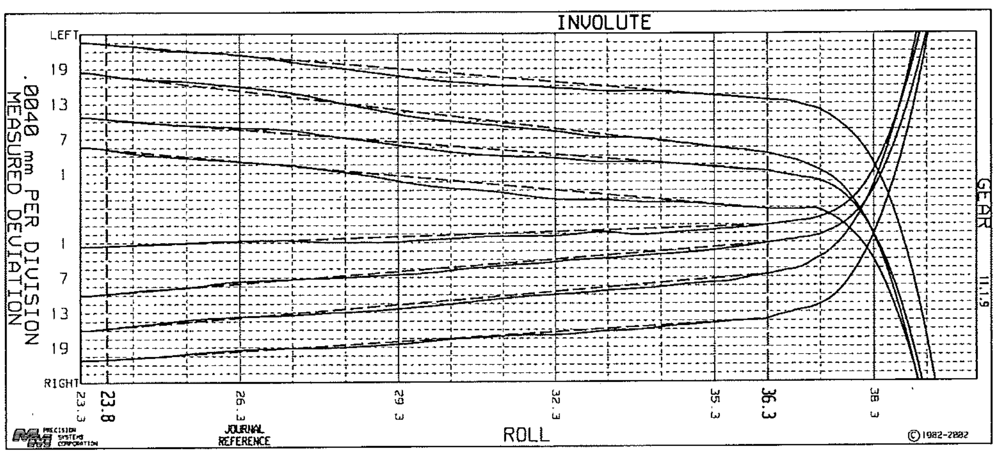


NOTE: "*" INDICATES OUT OF TOLERANCE

LEFT FLANK				RIGHT FLANK			
TOOTH	SLOPE	HOLLOW	CROWN	TOOTH	SLOPE	HOLLOW	CROWN
1	-.0150	.0028	.0021	1	.0141	.0088	.0000
7	-.0181	.0060	.0000	7	.0197	.0079	.0000
13	-.0382	.0006	.0036	13	.0305	.0091	.0000
19	-.0177	.0125	.0000	19	.0251	.0027	.0020

CONSTRUCTION LINE TYPE ANALYSIS

	LEFT FLANK		RIGHT FLANK
AVERAGE SLOPE	-.0223		.0224
AVERAGE CROWN	.0014		.0005
MAXIMUM HOLLOW	.0125		.0091
MAX SLOPE VAR	.0232		.0164
HELIX ANGLE	9.1941°	ERROR +.1941°	



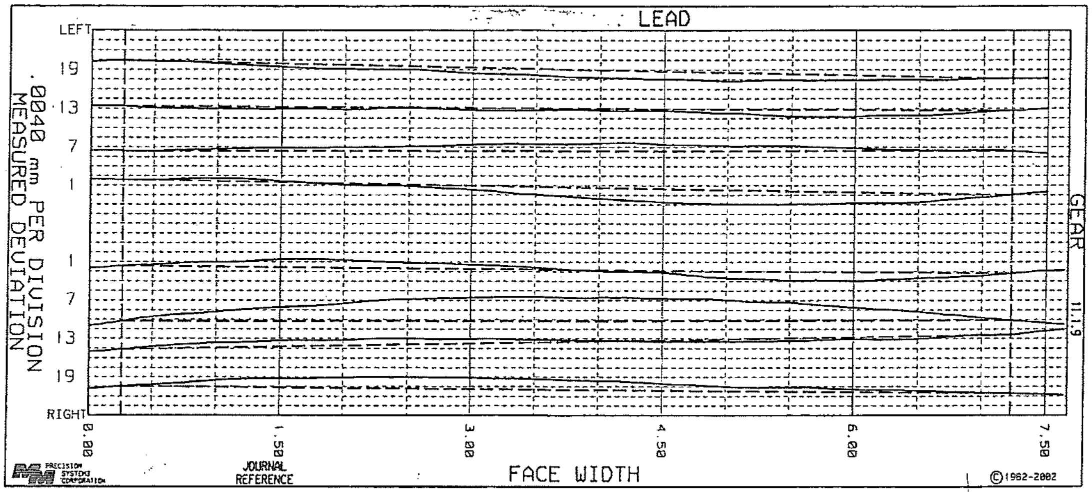
NOTE: "*" INDICATES OUT OF TOLERANCE

LEFT FLANK				RIGHT FLANK			
TOOTH	SLOPE	HOLLOW	CROWN	TOOTH	SLOPE	HOLLOW	CROWN
1	-.0280	.0044	.0003	1	-.0092	.0005	.0026
7	-.0242	.0030	.0016	7	-.0229	.0010	.0017
13	-.0362	.0026	.0020	13	-.0246	.0010	.0019
19	-.0260	.0040	.0003	19	-.0182	.0006	.0015

CONSTRUCTION LINE TYPE ANALYSIS

	LEFT FLANK	RIGHT FLANK
AVERAGE SLOPE	-.0286	-.0187
AVERAGE CROWN	.0010	.0019
MAXIMUM HOLLOW	.0044	.0010
MAX SLOPE VAR	.0120	.0154

Figure 7
(Before rework)

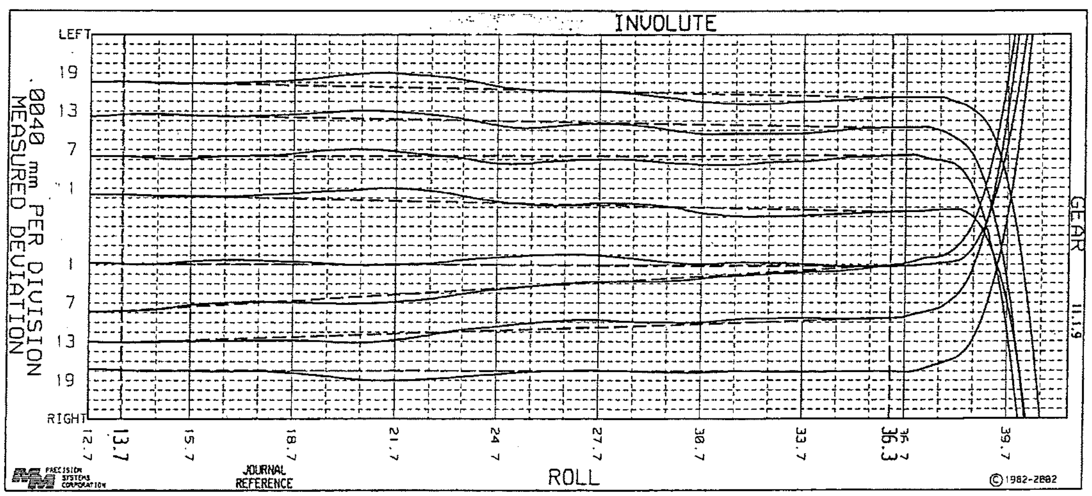


NOTE: "*" INDICATES OUT OF TOLERANCE

LEFT FLANK				RIGHT FLANK			
TOOTH	SLOPE	HOLLOW	CROWN	TOOTH	SLOPE	HOLLOW	CROWN
1	-.0063	.0059	.0013	1	.0031	.0035	.0036
7	.0000	.0001	.0034	7	-.0003	.0101	.0000
13	-.0019	.0030	.0000	13	-.0061	.0026	.0013
19	-.0073	.0035	.0001	19	.0030	.0049	.0000

CONSTRUCTION LINE TYPE ANALYSIS

	LEFT FLANK		RIGHT FLANK
AVERAGE SLOPE	-.0039		-.0001
AVERAGE CROWN	.0012		.0012
MAXIMUM HOLLOW	.0059		.0101
MAX SLOPE VAR	.0073		.0092
HELIX ANGLE	9.0163°	ERROR +.0163°	



NOTE: "*" INDICATES OUT OF TOLERANCE

LEFT FLANK				RIGHT FLANK			
TOOTH	SLOPE	HOLLOW	CROWN	TOOTH	SLOPE	HOLLOW	CROWN
1	-.0073	.0033	.0052	1	.0011	.0045	.0003
7	.0003	.0037	.0029	7	-.0190	.0009	.0031
13	-.0054	.0040	.0034	13	-.0099	.0033	.0032
19	-.0067	.0041	.0060	19	.0005	.0003	.0042

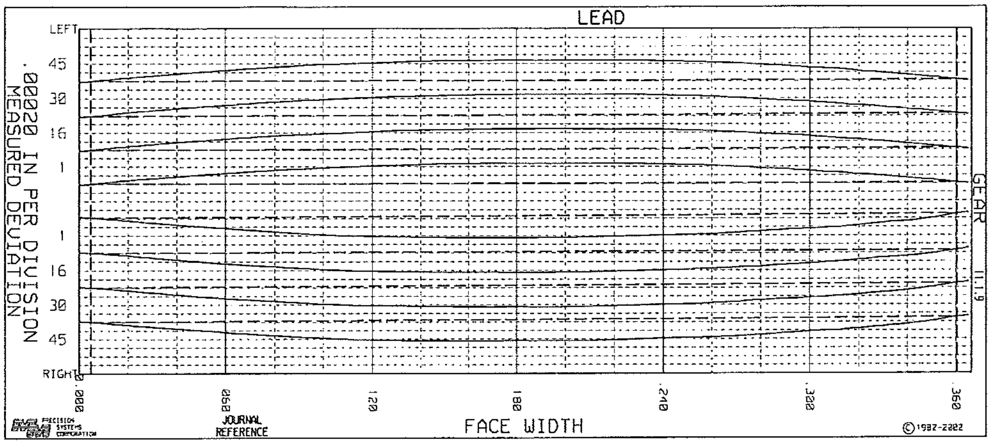
CONSTRUCTION LINE TYPE ANALYSIS

	LEFT FLANK	RIGHT FLANK
AVERAGE SLOPE	-.0048	-.0068
AVERAGE CROWN	.0044	.0027
MAXIMUM HOLLOW	.0041	.0045
MAX SLOPE VAR	.0076	.0201

Figure 8
(After rework)

Another advantage an elemental inspection has over other measuring systems is that it can check special features. One of these features would be crowning. Figure 9 shows some crowning along the lead. This is an

attractive modification when axial alignment may be an issue. The elemental inspection can verify the crown amount and location.



NOTE: "*" INDICATES OUT OF TOLERANCE

	LEFT FLANK				RIGHT FLANK		
TOOTH	SLOPE	HOLLOW	CROWN	TOOTH	SLOPE	HOLLOW	CROWN
1	.00003	.00000	.00047	1	-.00008	.00000	.00050
16	.00005	.00000	.00048	16	-.00006	.00000	.00048
30	.00006	.00000	.00048	30	-.00009	.00000	.00050
45	.00003	.00000	.00046	45	-.00010	.00000	.00050

CONSTRUCTION LINE TYPE ANALYSIS

	LEFT FLANK	RIGHT FLANK
AVERAGE SLOPE	.00004	-.00008
AVERAGE CROWN	.00047	.00050
MAXIMUM HOLLOW	.00000	.00000
MAX SLOPE VAR	.00003	.00005

Figure 9

Conclusions

Injection molding, with the attempts to predict part shrinkage, is still not an exact science. Even the gear of simplest design may not meet print specifications on the first trial. This will often lead to a second trial based on information learned from the first. With elemental measurement equipment, the problems can be defined and quantified, taking the guess work out of making corrections. After the corrections are made, the elemental inspection serves to verify the improvements.