TECHNOLOGY

CASE STUDY OF THE APPLICATION OF OIL AND HIGH PRESSURE GAS QUENCHING TO DISTORTION CRITICAL GEARS

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"The Heat Treat Doctor"®

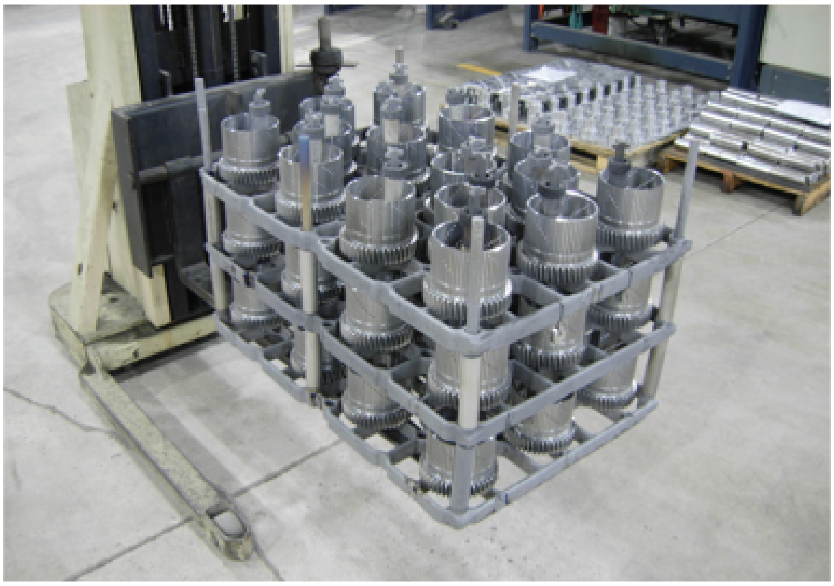
Highly distortion prone gearing (Fig. 1) was the subject of an investigation into the dimensional changes that result from utilizing either oil or high pressure gas quenching following a low pressure vacuum carburising process. The gears in question were atmosphere gas carburized and plug quenched in production, which was the standard practice for these geometries and the baseline for comparison.

Figure 1 | SAE 8620 Test Gears

Test Plan

Full production loads (Fig. 2) were run using two different carburising methods (atmosphere, vacuum) in combination with free quenching in either oil at 75°C (165°F) or high-pressure gas (nitrogen) at 11 bar.

Figure 2 | Typical Furnace Load Weighing 385 kg (850 lbs.)



Process Parameters

Carburising was performed at 960°C (1760°F) for 3.34 hours followed by either oil quenching with variable agitator speed or high-pressure gas quenching with variable gas speed and pressure. Targeted surface carbon content was 0.72%C (vacuum) and 0.80 -0.90%C (atmosphere). Gas quenching utilized four changes in speed and pressure made through the critical transformation range of the material while the oil quench utilized two changes in speed (70% and 40%). Tempering was performed at 150°C (300°F) for two hours at temperature.

Sampling Method

Gears were taken from multiple locations throughout each load for analysis (Table 1). Parts for metallurgical evaluation were selected from the center of each load. Multiple areas on each part were then analyzed for microstructure, case depth, and hardness (surface, profile, core).

Dimensional checks (out of round, gear tooth profiles) were conducted on the gears before and after heat treatment. Although only a portion of the complete test program is presented here, the results are representative of the entire study.

Table 1 | Test Sample Matrix

Gear type	**Test location(s)**	**Test area**	**Heat-treat method[a]**	**Condition [a] (for dimensional testing)**
A (Fig. 3)	S = Spline T = Tooth	I = mid-point II = root III = tip	1 = LPC + HPGQ 2 = LPC + OQ 3 = AC + OPQ	BHT AHT
B (Fig. 4)	S = Spline	I = mid-point II = root III = tip	1 = LPC + HPGQ 2 = LPC + OQ 3 = AC + OPQ	BHT AHT
C (Fig. 5)	S = Spline	I = mid-point II = root III = tip	1 = LPC + HPGQ 2 = LPC + OQ 3 = AC + OPQ	BHT AHT

Notes:

a. Abbreviations used: low pressure carburising (LPC), high pressure gas quenching (HPGQ), oil quench (OQ), atmosphere carburising (AC) and oil plug quench (OPQ); before heat treatment (BHT); and after heat treatment (AHT)

b. Existing heat treatment method is atmosphere carburising (AC) and plug quenching (OPQ).

Figure 3 | 150 mm (6”) diameter clutch gear; test gear type “A”

Figure 4 | 100 mm (4”) clutch hub; test gear type “B”

Figure 5 | 150 mm (6”) clutch hub; test gear type “C”

Test Results - Hardness

A review of the test data (Table 2) revealed the surface hardness of all low-pressure vacuum carburized gears was in the 64 – 65 HRC range. The surface hardness of the atmosphere carburized gears was in the 62 – 63 HRC range (due to the presence of higher percentages of retained austenite).

The depth of high hardness (> 58 HRC) was 0.05 – 0.13 mm (0.002” – 0.005”) deeper for the low-pressure vacuum carburized gears than for the atmosphere-carburized gears. The root-to-pitch line case depth ratio was 92 – 94% (vacuum carburising) versus 63% (atmosphere carburising).

Table 35.7.2 | Effective case depth (50 HRC) and depth of high hardness ≥ 58 HRC

	Heat-treat method 1 (lpc + HPGQ)		**Heat-treat method 2 (lpc + OQ)**		**Heat-treat method 3 (AC + OPQ)**	
	50HRC	>58HRC	50HRC	>58HRC	50HRC	>58HRC
	mm (inches)	mm (inches)	mm (inches)	mm (inches)	mm (inches)	mm (inches)
A						
Gear Tooth (mid-radius)	1,17 (0.046)	0,86 (0.034)	1,19 (0.047)	0,91 (0.036)	1,30 (0.051)	0,81 (0.032)
Gear Tooth (root)	1,07 (0.042)	0,81 (0.032)	1,12 (0.044)	0,84 (0.033)	1,14 (0.045)	0,76 (0.030)
Spline (mid-point)	1,40 (0.055)	1,12 (0.044)	1,42 (0.056)	1,19 (0.047)	1,47 (0.058)	0,99 (0.039)
Spline (root)	1,30 (0.051)	1,02 (0.040)	1,37 (0.054)	1,09 (0.043)	1,32 (0.052)	0,97 (0.038)

B						
Spline (mid-point)	1,37 (0.054)	1,07 (0.042)	1,42 (0.056)	1,14 (0.045)	1,55 (0.061)	0,97 (0.038)
Spline (root)	1,27 (0.050)	1,02 (0.040)	1,35 (0.053)	1,07 (0.042)	1,52 (0.060)	0,89 (0.035)
C						
Spline (mid-point)	1,37 (0.054)	1,07 (0.042)	1,45 (0.057)	1,22 (0.048)	1,55 (0.061)	0,97 (0.038)
Spline (root)	1,30 (0.051)	1,04 (0.041)	1,37 (0.054)	1,12 (0.044)	1,52 (0.060)	0,91 (0.036)

The hardness data for various locations on each test gears (Tables 3 – 6) provides a relative comparison of each test method by location (tooth or spline).

Table 3 | Hardness profile gear type "A"; test location: gear tooth

Depth inches (mm)	**Heat treat method 1 (mid-tooth)**	**Heat treat method 1 (root)**	**Heat treat method 2 (mid-radius)**	**Heat treat method 2 (root)**	**Heat treat method 3 (mid-tooth)**	**Heat treat method 3 (root)**
0.005 (0.13)	64	63	65	64	63	63
0.010 (0.25)	64	62	64	63	63	63
0.015 (0.38)	64	61	64	62	62	62
0.020 (0.51)	63	60	64	61	62	61
0.025 (0.64)	62	59	62	60	61	60
0.030 (0.76)	59	58	61	59	58	58
0.035 (0.89)	57	54	59	54	57	56

0.040 (1.01)		54		51		55		52		56		53
0.045 (1.14)		50		47		52		50		53		50
0.050 (1.27)		48		45		49		46		50		47
0.055 (1.40)		39		41		44		43		48		43
0.060 (1.52)		38		38		40		39		44		40
Core		30		29		36		35		36		35

Table 4 | Hardness profile gear type “A”; test location: spline

Depth		**Heat treat method 1 gear type “A” (mid-point)**	**Heat treat method 1 gear type “B” (mid-point)**	**Heat treat method 1 gear type “C” (mid-point)**		**Heat treat method 1 gear type “A” (roo t)**	**Heat treat method 1 gear type “B” (root)**	**Heat treat method 1 gear type “C” (root)**
0.005 (0.13)		65	65	65		65	63	64
0.010 (0.25)		65	64	65		65	64	64
0.015 (0.38)		65	65	64		63	64	64
0.020 (0.51)		65	64	64		63	61	63
0.025 (0.64)		64	63	64		63	60	60
0.030 (0.76)		63	62	62		61	59	60
0.035 (0.89)		61	60	61		60	58	59

0.040 (1.01)		60	59	59		58	56	58
0.045 (1.14)		57	56	56		54	48	54
0.050 (1.27)		54	51	53		50	40	51
0.055 (1.40)		50	47	49		46	43	47
0.060 (1.52)		46	43	45		44	39	44
Core		34	34	35		33	32	32

Table 5 | Hardness profile gear type “B”; test location: spline

Depth		**Heat treat method 2 gear type “A” (mid-point)**	**Heat treat method 2 gear type “B” (mid-point)**	**Heat treat method 2 gear type “C” (mid-point)**		**Heat treat method 1 gear type “A” (root)**	**Heat treat method 1 gear type “B” (root)**	**Heat treat method 1 gear type “C” (root)**
0.005 (0.13)		64	65	65		65	65	64
0.010 (0.25)		64	65	64		65	64	64
0.015 (0.38)		64	65	64		64	64	64
0.020 (0.51)		63	64	63		63	63	63
0.025 (0.64)		63	63	62		62	62	62
0.030 (0.76)		62	62	61		61	61	61
0.035 (0.89)		60	61	60		60	60	60

0.040 (1.01)		59	60	60		59	58	59
0.045 (1.14)		58	58	58		54	56	58
0.050 (1.27)		54	54	55		51	53	54
0.055 (1.40)		51	50	50		49	50	49
0.060 (1.52)		48	47	49		46	47	46
Core		38	37	38.5		37	36	37

Table 6 | Hardness profile gear type “C”; test location: spline

Depth		**Heat Treat Method 3 Gear Type “A” (mid-point)**	**Heat Treat Method 3 Gear Type “B” (mid-point)**	**Heat Treat Method 3 Gear Type “C” (mid-point)**		**Heat treat method 1 gear type “A” (roo t)**	**Heat treat method 1 gear type “B” (root)**	**Heat treat method 1 gear type “C” (root)**
0.005 (0.13)		62	62	64		63	62	63
0.010 (0.25)		62	63	65		63	63	64
0.015 (0.38)		63	64	64		62	64	64
0.020 (0.51)		63	64	63		61	62	62
0.025 (0.64)		63	63	63		63	61	61
0.030 (0.76)		61	61	62		61	59	60
0.035 (0.89)		60	60	60		59	58	58

0.040 (1.01)		57	57	57		57	55	57
0.045 (1.14)		56	55	56		54	53	55
0.050 (1.27)		55	54	54		50	52	52
0.055 (1.40)		53	52	52		49	51	51
0.060 (1.52)		49	50	50		46	50	50
Core		36	35	36		35	36	37

Test Results - Distortion

Dimensional variation was determined by measuring both out of round (Table 7) and by coordinate measuring machine (CMM) measurement of the gear tooth profiles (Fig Nos. 6 - 13). With respect to the gear charts, the lead was measured across the tooth or spline from side to side at the pitch diameter. This method was checked for excessive taper. The involute measurements were taken on the tooth form (active profile), starting from the root diameter to the tip of the tooth. Indexing (index error) measured the tooth spacing from tooth to tooth around the gear. Gear or spline run-out measured variation of concentricity of the centerline (datum) of the gear.

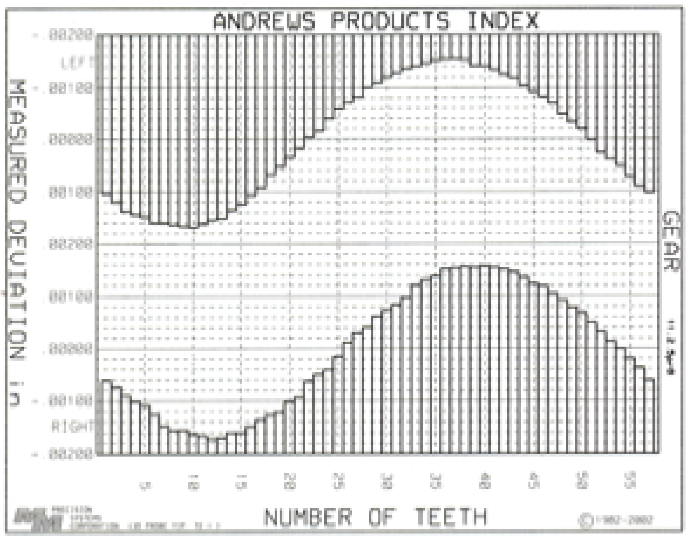
All gears and all heat treatment methods were checked by the aforementioned methods but space precludes inclusion of all the data so the high-pressure gas quench gear results have been selected for presentation here.

Table 7 | Out of round (spline)

Gear Type	Test Locations	**Heat Treat Method 1 (LPC+HPGQ) mm (inches)**	**Heat Treat Method 2 (LPC+OQ) mm (inches)**	**Heat Treat Method 3 (AC+OQ) mm (inches)**
A	top	0,1320 (0.0052)	0,3962 (0.0156)	1,0668 (0.0420)
	middle	0,0838 (0.0033)	0,2413 (0.0095)	0,5715 (0.0225)
	bottom	0,0431 (0.0017)	0,1574 (0.0062)	0,4115 (0.0162)
B	top	0,1117 (0.0044)	0,3530 (0.0139)	0,8737 (0.0344)
	middle	0,0787 (0.0031)	0,2311 (0.0091)	0,5156 (0.0203)
	bottom	0,0457 (0.0018)	0,1473 (0.0058)	0,3479 (0.0137)
C	top	0,0939 (0.0037)	0,3225 (0.0127)	0,7061 (0.0278)
	middle	0,0812 (0.0032)	0,2133 (0.0084)	0,4165 (0.0164)
	bottom	0,0406 (0.0016)	0,1066 (0.0042)	0,3022 (0.0119)

Notes:
The existing heat-treating method (atmosphere carburising and plug quenching) results in out of round values typically in the range of 0.0508 – 0.0762 mm (0.002" – 0.003").

Figure 6 | Sample "C" before heat-treat



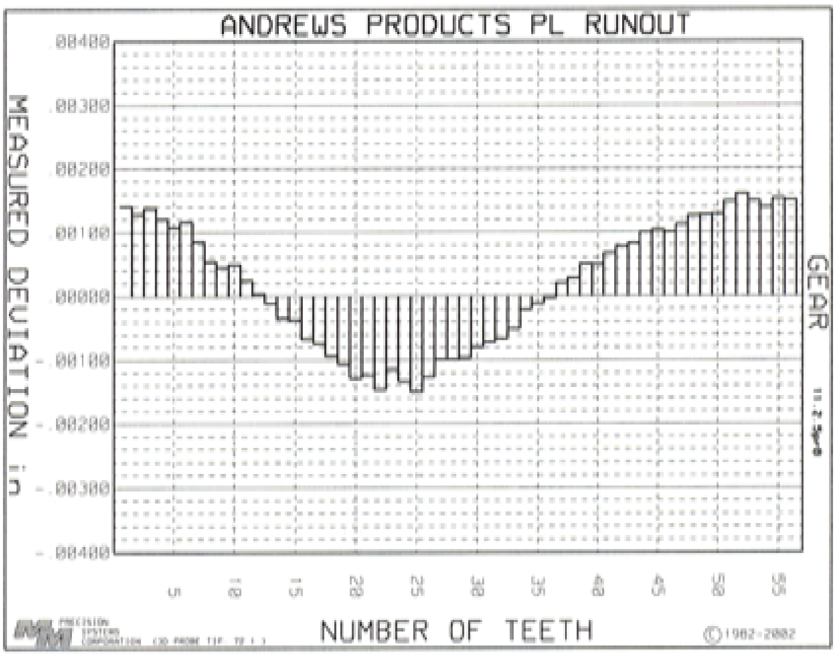
LEFT FLANK
TOTAL INDEX VARIATION * .00323 in*
TOLERANCE .00150 in
WORST PITCH VARIATION .00024 in TEETH 51 AND 52
TOLERANCE .00042 in
WORST SPACING VARIATION .00013 in TEETH 12, 13 AND 14

RIGHT FLANK
TOTAL INDEX VARIATION * .00329 in*
TOLERANCE .00150 in
WORST PITCH VARIATION .00030 in TEETH 21 AND 22
TOLERANCE .00042 in
WORST SPACING VARIATION .00020 in TEETH 20, 21 AND 22

ANALYZED RUNOUT .00312 in AT 45.7°

AGMA CLASS SPECIFIED Q10, CLASS ACHIEVED Q11
WARNING: PITCH LINE VARIATION EXCEEDS AGMA RUNOUT TOLERANCE

Figure 7 | Sample "C" before heat-treat



TOTAL PL VARIATION * .00310 in*
TOLERANCE .00150 in

ANALYZED RUNOUT .00312 in AT 45.7°

WARNING: PITCH LINE VARIATION EXCEEDS AGMA RUNOUT TOLERANCE

Figure 8 | Sample "C" before heat-treat

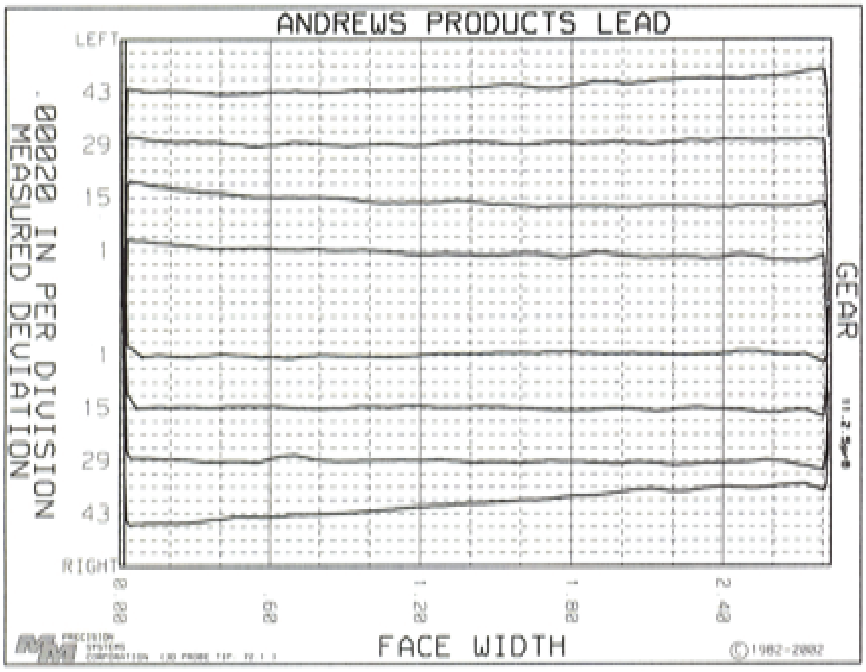


Figure 9 | Sample "C" before heat-treat

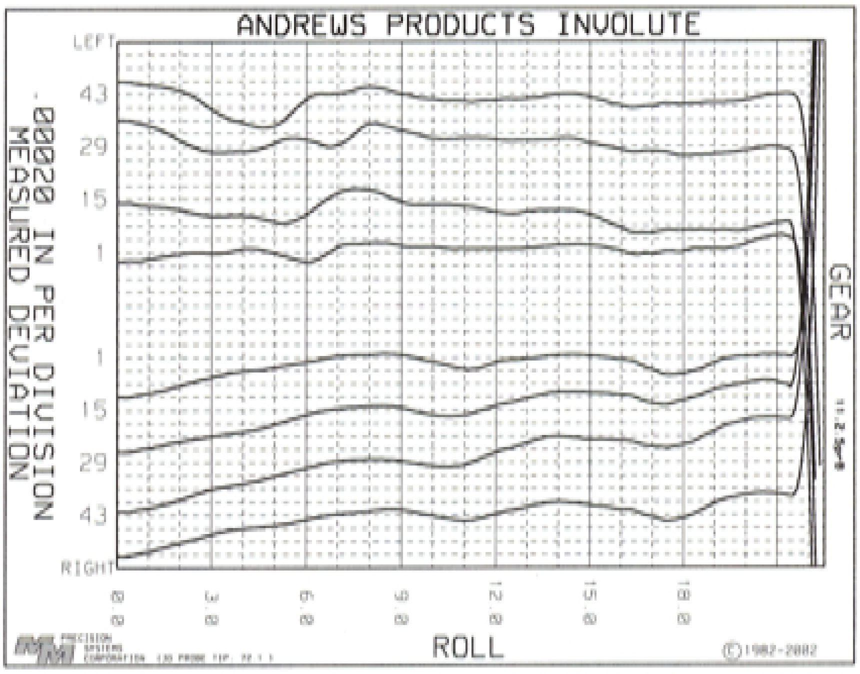
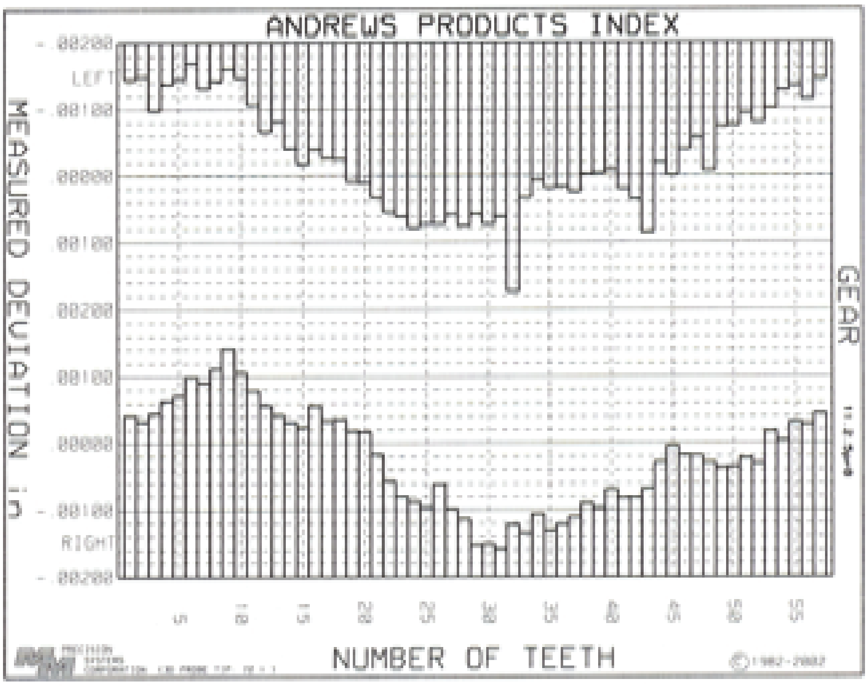


Figure 10 | Sample "C" after heat-treat (LPC + HPGQ)

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LEFT FLANK
TOTAL INDEX VARIATION          .00342 in
WORST PITCH VARIATION         -.00140 in TEETH 32 AND 33
WORST SPACING VARIATION        .00251 in TEETH 31, 32 AND 33

RIGHT FLANK
TOTAL INDEX VARIATION          .00299 in
WORST PITCH VARIATION          .00048 in TEETH 52 AND 53
WORST SPACING VARIATION        .00072 in TEETH 25, 26 AND 27

ANALYZED RUNOUT                .00200 in AT 190.8°
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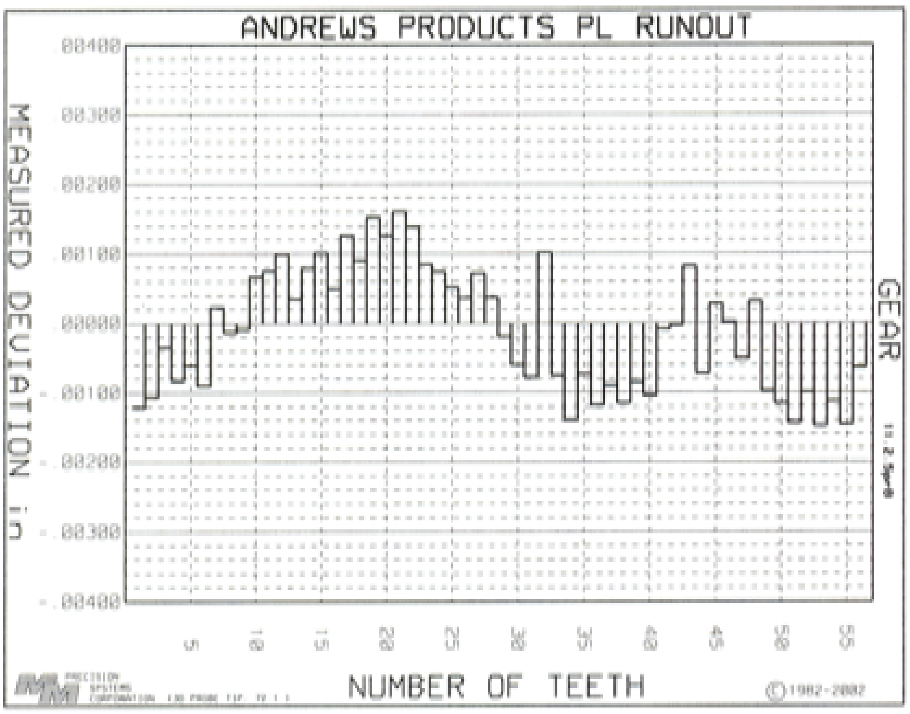
Figure 11 | Sample "C" after heat-treat (LPC + HPGQ)

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TOTAL PL VARIATION     *   .00308 in*
 TOLERANCE                 .00150 in

ANALYZED RUNOUT            .00200 in AT 190.8°
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Figure 12 | Sample "C" after heat-treat (LPC + HPGQ)

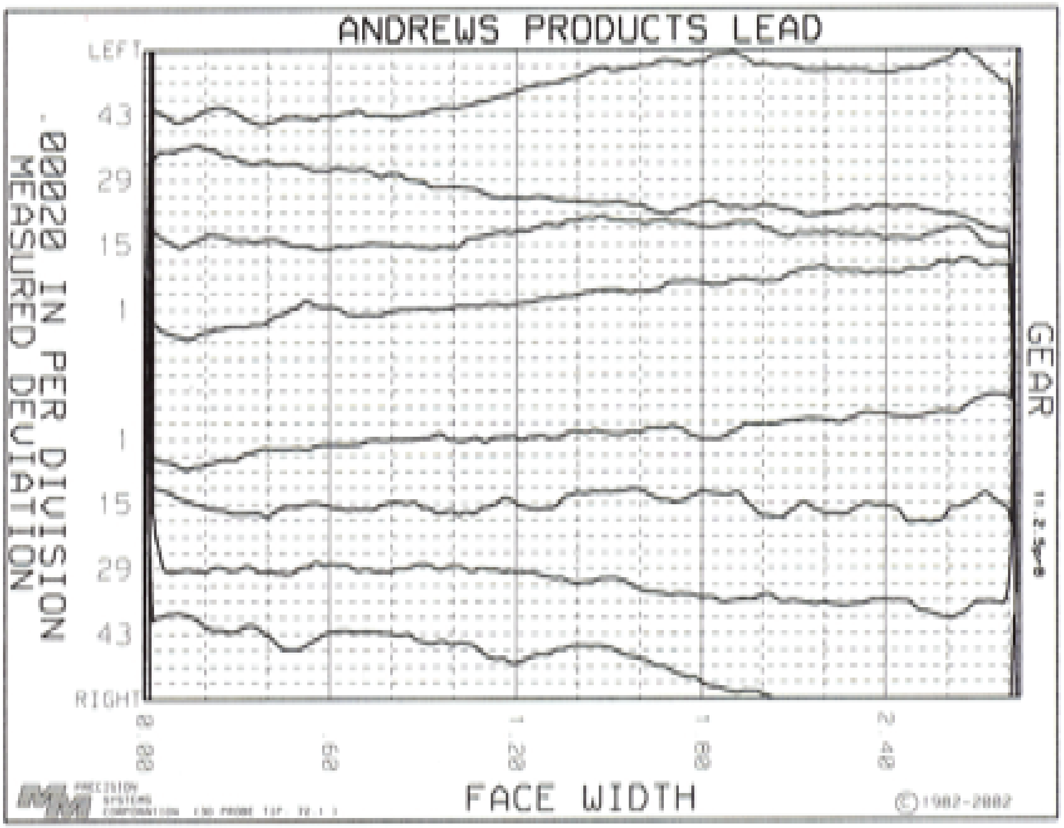
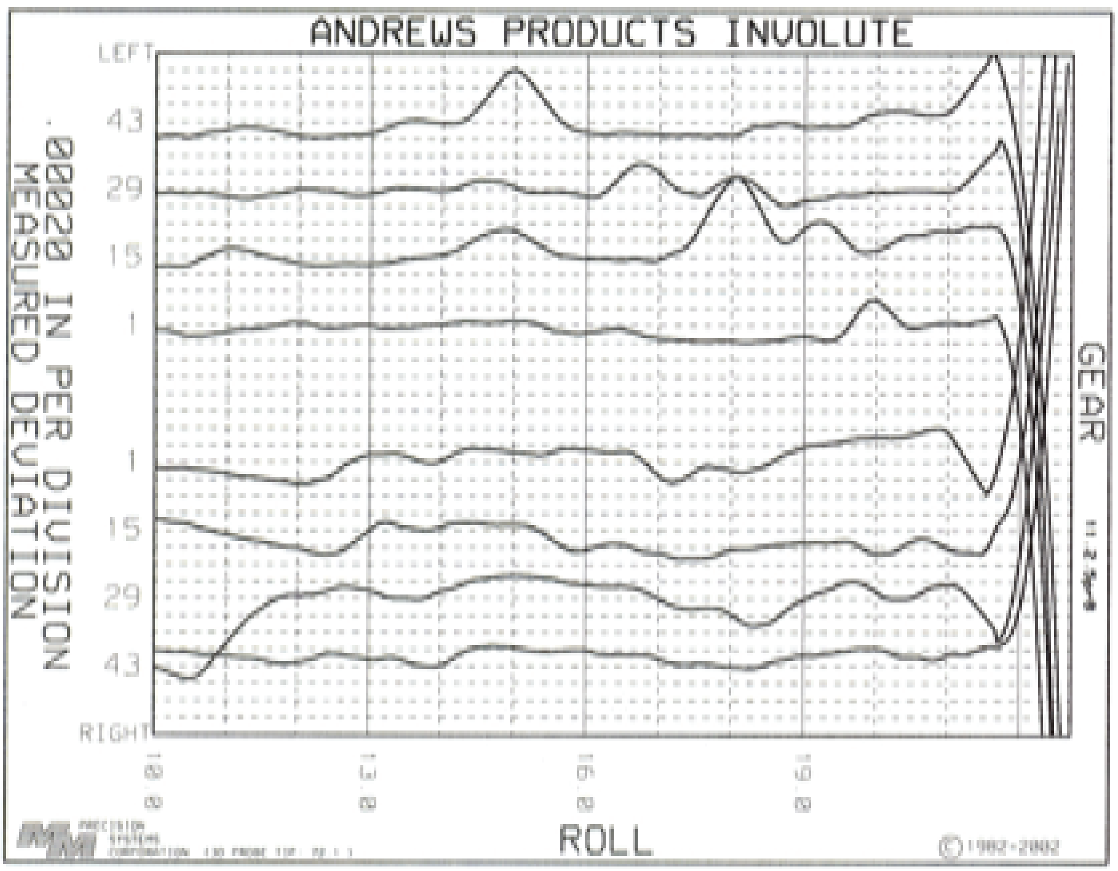


Figure 13 | Sample "C" after heat-treat (LPC + HPGQ)



Test Results – Microstructure

Analysis of part microstructures was taken from all areas (tip, mid-radius, root) and in the case of vacuum carburising (Fig. 14) revealed a tempered martensite structure with small amounts of retained austenite. Atmosphere carburized gears (Fig.15) revealed the presence of large amounts of retained austenite (tip, mid-radius).
Once again, all gears and all locations were metallurgically evaluated and the figures shown here are representative of the results in all cases.

Figure No. 14 | Clutch gear "C", gear tooth mid-radius, LPC + HPGQ (1250X, 2% Nital)

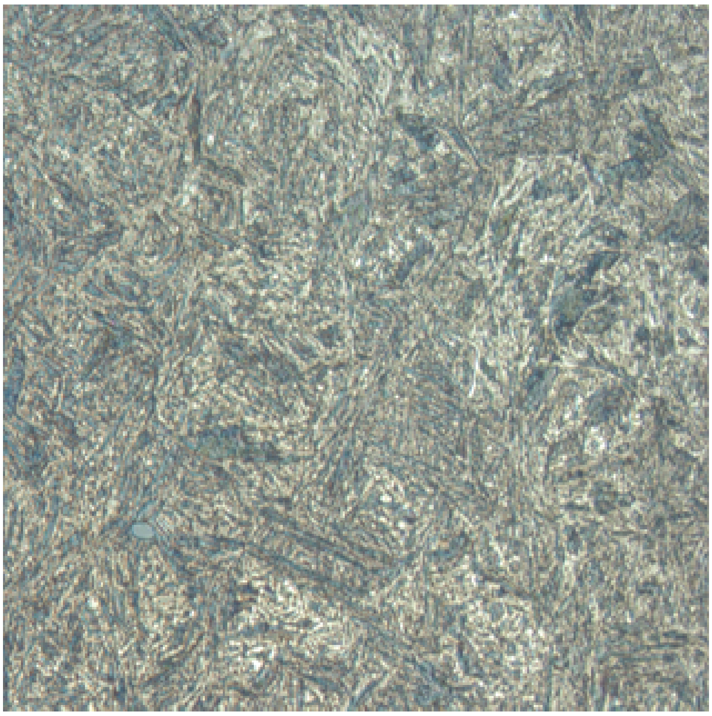
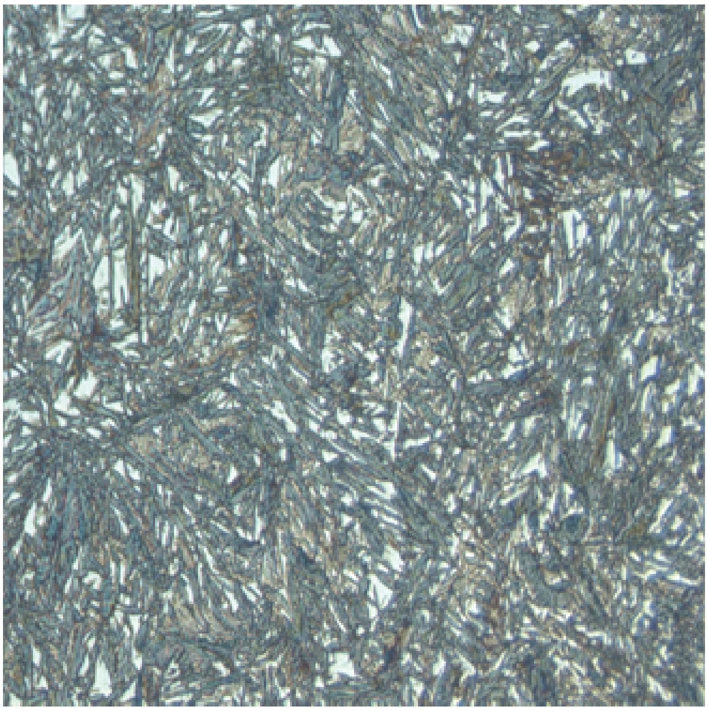


Figure No. 15 | Clutch gear "C", gear tooth mid-radius, AC + OPQ, (1250X, 2% Nital)



Test Conclusions

The following are the principal results of these trials:

1. High-pressure gas and oil quenching produced more consistent dimensional repeatability on the gear geometries in this study.
   a. This degree of predictable movement could be anticipated in the pre-heat treatment manufacturing process thus avoiding significant post heat treatment grinding.
2. Gear charts indicated an average movement of 0,076 mm (0.003").
   a.The involute form remained intact after high-pressure gas and oil quenching as did the lead on the gear teeth and splines.
3. ow-pressure vacuum carburising in combination with oil or high-pressure gas quenching allowed for the replacement of atmosphere carburising and plug quenching on the gears investigated in this study.
   a. The depth of high hardness (> 58 HRC) was greatest in the low-pressure vacuum carburised samples.
   b. The root-to-pitch line case depth ratio in vacuum carburising (93%) exceeded that of atmosphere carburising 63%).
   c. Levels of retained austenite were higher in the atmosphere-carburized samples.

Special Acknowledgement

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References

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