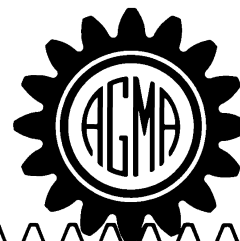


Modelling Gear Distortion

by: P.C. Clarke, David Brown Heatech

American Gear Manufacturers Association



TECHNICAL PAPER

Modelling Gear Distortion

Philip C. Clarke, David Brown Heatech

[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

Dealing with carburize case hardened gear distortion and growth is a challenge for the global gear industry. Attempts started in 1978 with computer programs to calculate distortion and growth, plus residual stress distributions for a gear and evolved by gathering distortion data for a wide range of sizes, shapes, grinding allowances with trends for different geometries. A spread sheet program with gear dimensional input, calculates the distortions and growths, and then calculates the modified dimensions for required protuberance and the minimum carburized case depth. Case histories illustrate the consequences of various geometries and future developments are discussed.

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Modelling Gear Distortion

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Introduction

For high quality carburise case hardened gears a predictive capability combined with close control over distortion and growth is essential.

ASM Handbook Volume 4, ref 1, defines distortion as "An irreversible and usually unpredictable change of size and shape".

This paper seeks to show that there is predictability and change of shape is not always irreversible.

Initial Developments

Our first driver for a better understanding of distortion was dealing with a large face width, double helical gear, ref 2-5. This had 178 x 5.08 module (5DP) teeth, measured 36" on the outside diameter and weighed in at 2.4 tonnes - see Figure 1.

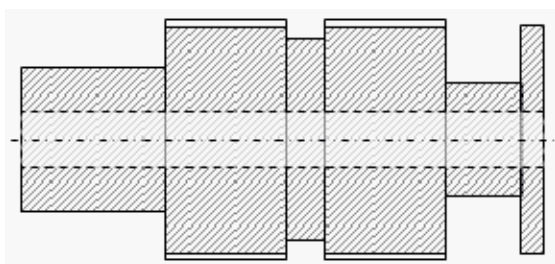


Figure 1. Marine Gear Wheel Schematic

In 1978 a research contract was placed by the MOD(N), the British naval procurement agency, on David Brown to develop a suite of programs to predict distortion and growth plus residual stress distributions for the above gear wheel.

Partial Success was achieved by:

- ◆ Modelling CCT diagrams and calculating metallurgical transformations during cooling and heating.
- ◆ Defining a correlation between cast analysis and growth.
- ◆ Accurately predicting final case and core hardnesses, ref 6.

Figure 2 shows the core micro-structural distributions when the tooth roots attain the carburising temperature during heating.

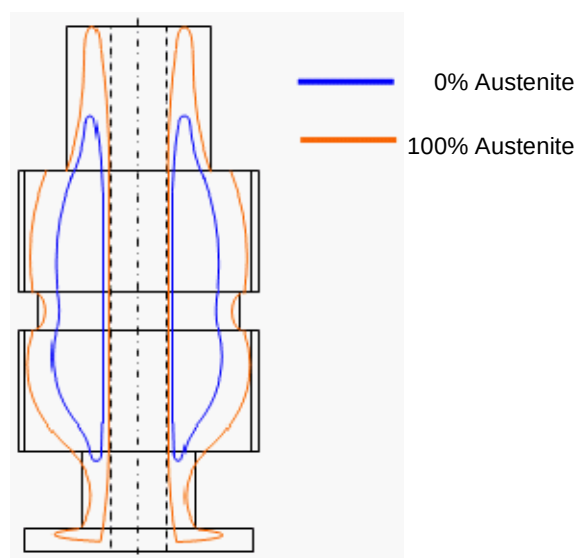


Figure 2. Core Microstructural distributions when the tooth roots attain the Carburising Temperature

However, attempts to achieve the final objective were thwarted by:

- ◆ A dearth of theoretical models.
- ◆ Little data on the mechanical properties of individual phases at temperature and during transformation.
- ◆ No data for the effect of stress on transformation
- ◆ Poor computing power.

A Pragmatic Approach

Distortion remained a huge problem because we make large numbers of unique large gears and not being 'right first time' is unacceptable.

A pragmatic approach was adopted starting in the early 1980's.

This required the:

- ◆ Gathering of historical and new data for a wide range of gear geometries and sizes.

■ Analysis and extraction of trends for specific geometries.

Figure 3 shows the variation of taper with outside diameter (OD) for gear wheels. Figure 4 shows how out of roundness (Ovality) varies with outside diameter for large ring gears.

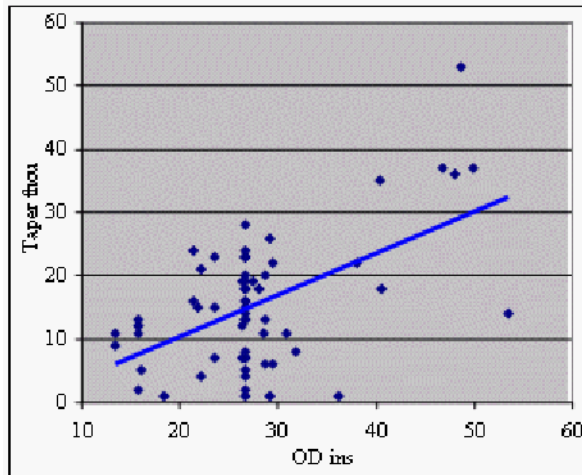


Figure 3. Gear Wheel OD Taper vs OD

Whilst there are clear trends the scatter is large. One clear objective when managing distortion is to reduce this scatter.

As data was collected trends, which depend on shape, emerged. Figure 5 shows the variation of growth rate (thou per inch of outside diameter) with length/wall thickness ratio. This observation led to the first classification of shapes as a function of shape as illustrated in Figure 6.

This classification applies to:

1. Gears heat treated with the major axis vertical as illustrated in Figures 2, 7 and 9.
2. All gear materials provided that core hardenability is matched to section size to achieve core hardnesses between 300 and 400 HV.

This classification was the key to the first David Brown standard, ref 7, giving distortion and growth allowances for six shapes. Figure 7 is an extract from the standard.

These allowances were incorporated in 1987 into the CAD system from which prior and post heat treatment tooth sizes were calculated. Appendix 1 shows a sample output page.

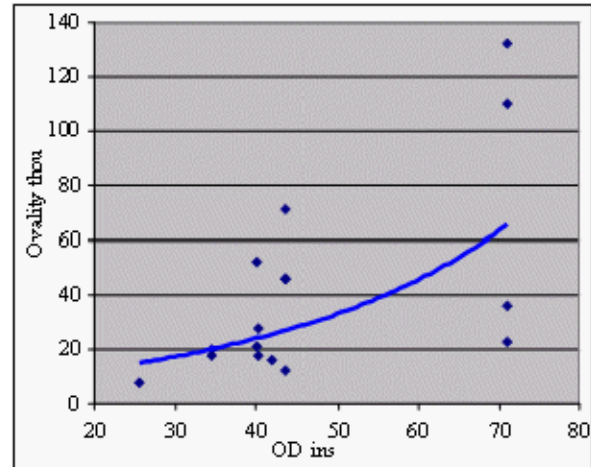


Figure 4. Ring Gear Ovality vs OD

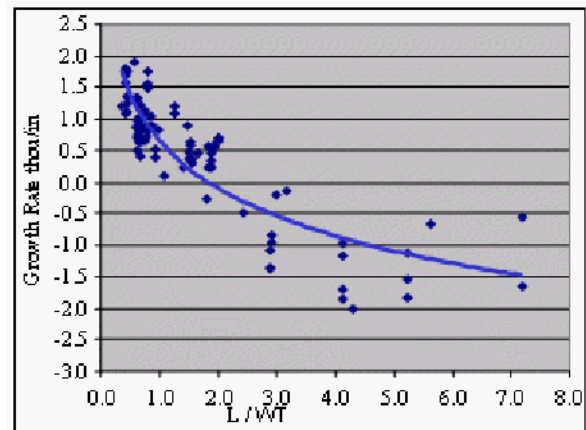


Figure 5. Growth Rate vs Length / Wall Thickness

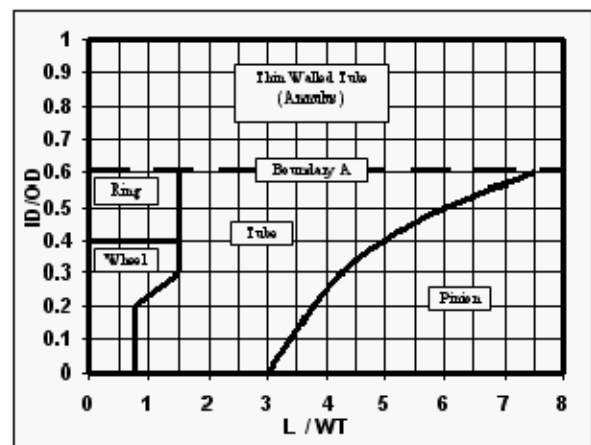
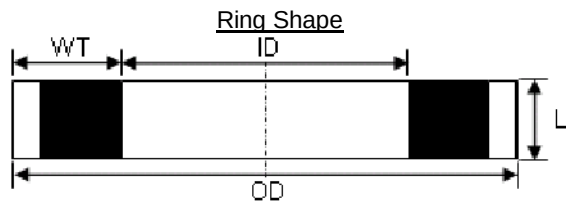


Figure 6. Classification of Shapes



Shape Limitations a) $\frac{L}{WT} \leq 1.5$ b) $\frac{ID}{OD} > 0.4$

c) Minimum Wall Thickness ⁽¹⁾ [WT] in mm is defined by the formula:

$$WT = 2.25 \times \text{mod} + 0.4 \times \sqrt[5]{\text{mod} \times L \times OD^3}$$

Outside Diameter Limits	Distortion and Growth Allowance	Heat Treatment Procedures
Less than or equal to 20 in	1) No growth allowance 2) Normal grinding allowance	1) Axis vertical at each stage
Over 20 in and less than or equal to 38 in ⁽²⁾	1) No growth allowance 2) Special grinding allowance ⁽³⁾ 3) Increased case depth ⁽³⁾	2) Support at 3 points 120° apart circumferentially at each stage.
Over 38 in Subcontracting required	1) Growth allowance .0005 in per in O.D. 2) Special grinding allowance 3) Increased case depth Consult Metallurgy Department	1) Axis vertical at each stage. (a) Largest O.D. uppermost. (b) Step Heat (c) Support at 3 points 120° apart circumferentially.

Table Notes

- 1) The minimum wall thickness is a design minimum requirement except for gears of less than 25 in O.D. and less than 50 Kg in weight which are to be treated as thin walled tubes.
- 2) 38 in O.D. is the limit for gas carburising at Park Works.
- 3) Until further experience is gained of these sizes.

General Note

The basic helix angle at hobbing is to be reduced by 0° 02'00" if:

- (1) The base angle helix exceeds 15° and,
- (2) The O.D. is greater than 15 in.

Figure 7. Extract from Distortion and Growth Standard

Managing Distortion and Growth

Having defined the trends and identified the scatter this experience was applied to a specific product range with the objectives of introducing control measures to reduce both the levels and the scatter of distortion, ref 8.

This involved the measurement of all key dimensions before and after each stage of heat treatment.

For the gear wheels by changing the stacking arrangement, increasing spacing between gears and improving support, see Figure 8, taper and ovality of outside diameter, out of flatness and cumulative pitch errors were reduced and became more consistent. Figures 9 and 10 show the effects of these measures on these distortions.

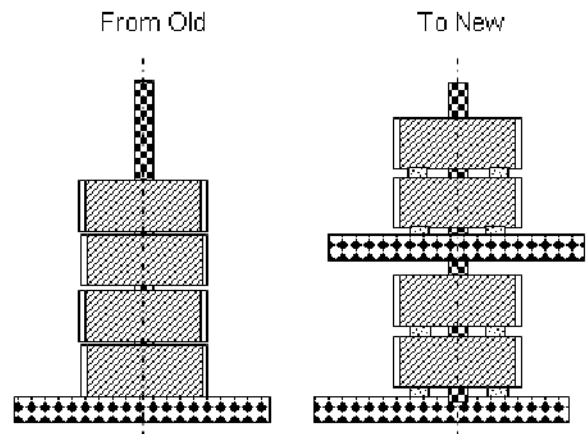


Figure 8. Changing Stacking of Gear Wheels

The significance of cumulative pitch error also emerged. Cumulative pitch error is a large element of gear wheel distortion and shows little correlation with other distortions and growths such as OD taper, ovality, growth and out of flatness.

This means that if a gear wheel is almost round, untapered and flat then cumulative pitch remains and can represent up to 90% of the grinding stock removal required to clean up the teeth.

This project also looked at pinions. Measures taken resulted in reductions of out of straightness of up to 75%.