American National Standard

Appearance of Gear Teeth - Terminology of Wear and Failure
Appearance of Gear Teeth - Terminology of Wear and Failure

ANSI/AGMA 1010-F14

[Revision of ANSI/AGMA 1010-E95]

Approval of an American National Standard requires verification by ANSI that the requirements for due process, consensus and other criteria for approval have been met by the standards developer.

Consensus is established when, in the judgment of the ANSI Board of Standards Review, substantial agreement has been reached by directly and materially affected interests. Substantial agreement means much more than a simple majority, but not necessarily unanimity. Consensus requires that all views and objections be considered, and that a concerted effort be made toward their resolution.

The use of American National Standards is completely voluntary; their existence does not in any respect preclude anyone, whether he has approved the standards or not, from manufacturing, marketing, purchasing or using products, processes or procedures not conforming to the standards.

The American National Standards Institute does not develop standards and will in no circumstances give an interpretation of any American National Standard. Moreover, no person shall have the right or authority to issue an interpretation of an American National Standard in the name of the American National Standards Institute. Requests for interpretation of this standard should be addressed to the American Gear Manufacturers Association.

CAUTION NOTICE: AGMA technical publications are subject to constant improvement, revision or withdrawal as dictated by experience. Any person who refers to any AGMA Technical Publication should be sure that the publication is the latest available from the Association on the subject matter.


Approved August 8, 2014

ABSTRACT

This nomenclature standard identifies and describes the classes of common gear failures and illustrates degrees of deterioration.

Published by

American Gear Manufacturers Association
1001 N. Fairfax Street, Suite 500, Alexandria, Virginia 22314

Copyright © 2014 by American Gear Manufacturers Association
All rights reserved.

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without prior written permission of the publisher.

Printed in the United States of America

ISBN: 978-1-61481-089-6
Contents
Foreword ...................................................................................................................................................... vii
1 Scope ..................................................................................................................................................... 1
2 Normative references .......................................................................................................................... 1
3 Definitions ........................................................................................................................................... 1
  3.1 Definitions ...................................................................................................................................... 1
  3.2 Classes and modes of failure ......................................................................................................... 2
4 Wear .................................................................................................................................................... 3
  4.1 Adhesion ......................................................................................................................................... 3
  4.1.1 Mild adhesion .......................................................................................................................... 4
  4.1.2 Moderate adhesion ................................................................................................................ 4
  4.1.3 Summary of methods to reduce the risk of adhesive wear .................................................. 5
  4.2 Abrasion ......................................................................................................................................... 5
  4.2.1 Mild abrasion .......................................................................................................................... 5
  4.2.2 Moderate abrasion ................................................................................................................ 6
  4.2.3 Severe abrasion ...................................................................................................................... 6
  4.2.4 Sources of particles that may cause wear ........................................................................... 8
  4.2.5 Methods for reducing abrasive wear .................................................................................. 8
  4.3 Polishing ........................................................................................................................................ 9
  4.3.1 Mild polishing ........................................................................................................................ 9
  4.3.2 Moderate polishing .............................................................................................................. 9
  4.3.3 Severe polishing ................................................................................................................... 9
  4.3.4 Summary of methods to reduce the risk of polishing wear ............................................. 10
  4.4 Corrosion ....................................................................................................................................... 10
  4.4.1 Methods to reduce the risk of corrosion ............................................................................. 11
  4.5 Fretting ......................................................................................................................................... 12
  4.5.1 True brinelling ..................................................................................................................... 12
  4.5.2 False brinelling .................................................................................................................. 13
  4.5.3 Fretting corrosion .............................................................................................................. 13
  4.5.4 Summary of methods to reduce the risk of false brinelling and fretting corrosion ........ 13
  4.6 Scaling ......................................................................................................................................... 14
  4.7 White layer flaking .................................................................................................................... 14
  4.7.1 Summary of methods to reduce the risk of white layer flaking ........................................ 15
  4.8 Cavitation ....................................................................................................................................... 15
  4.9 Erosion .......................................................................................................................................... 17
  4.10 Electric discharge ..................................................................................................................... 18
  4.10.1 Summary of methods to reduce the risk of electrical discharge damage ..................... 21
5 Scuffing .............................................................................................................................................. 21
  5.1 Mild scuffing ............................................................................................................................... 21
  5.2 Moderate scuffing ...................................................................................................................... 21
  5.3 Severe scuffing ............................................................................................................................ 23
  5.3.1 Methods for reducing the risk of scuffing ......................................................................... 25
  5.3.2 Summary of methods to reduce the risk of scuffing .......................................................... 26
6 Plastic deformation ............................................................................................................................. 26
  6.1 Indentation ..................................................................................................................................... 26
  6.2 Cold flow ....................................................................................................................................... 27
  6.3 Hot flow ....................................................................................................................................... 27
  6.4 Rolling .......................................................................................................................................... 27
6.5 Tooth hammer
6.6 Rippling
6.7 Ridging
6.8 Burr
6.9 Root fillet yielding
6.10 Tip-to-root interference
6.11 Tight mesh

7 Hertzian fatigue

7.1 Hertzian fatigue
7.1.1 Nonprogressive macropitting
7.1.2 Progressive macropitting
7.1.3 Point-surface-origin macropitting
7.1.4 Spall macropitting

7.2 Micropitting
7.2.1 Summary of methods to reduce the risk of micropitting

7.3 Subsurface initiated failures
7.3.1 Inclusion origin failures
7.3.2 Origins of nonmetallic inclusions

7.4 Subcase fatigue
7.4.1 Summary of methods to reduce the risk of subcase fatigue

8 Cracking and other surface damage

8.1 Hardening cracks
8.1.1 Thermal stresses
8.1.2 Stress concentration
8.1.3 Quench severity
8.1.4 Phase transformation
8.1.5 Steel grades
8.1.6 Part defects
8.1.7 Heat treating practice
8.1.8 Tempering practice
8.1.9 Summary of methods to reduce the risk of hardening cracks

8.2 Grinding damage
8.2.1 Grinding cracks
8.2.2 Overheating due to grinding
8.2.3 Summary of methods to reduce the risk of grinding cracks

8.3 Rim and web cracks
8.3.1 Summary of methods to reduce the risk of rim or web cracks

8.4 Case/core separation
8.4.1 Summary of methods to reduce the risk of case/core separation

8.5 Fatigue cracks

9 Fracture

9.1 Brittle fracture
9.1.1 Methods for reducing the risk of brittle fracture

9.2 Ductile fracture
9.3 Mixed mode fracture
9.4 Tooth shear
9.5 Fracture after plastic deformation
10 Bending fatigue ..................................................................................................................................... 61
  10.1 Low cycle fatigue ......................................................................................................................... 62
  10.2 High cycle fatigue .......................................................................................................................... 62
    10.2.1 Morphology of fatigue fracture surfaces .................................................................................. 63
    10.2.2 Summary of methods to reduce the risk of high-cycle bending fatigue .................................. 64
    10.2.3 Root fillet cracks ...................................................................................................................... 65
    10.2.4 Profile cracks ............................................................................................................................ 65
    10.2.5 Tooth end cracks ....................................................................................................................... 66
    10.2.6 Subsurface initiated bending fatigue cracks .......................................................................... 66
    10.2.7 Tooth interior fatigue fracture, TIFF ...................................................................................... 73

Annexes
Annex A Design considerations to reduce the chance of failure .......................................................... 75
Annex B Bibliography .................................................................................................................................. 79
Annex C Acknowledgements .................................................................................................................. 81

Tables
Table 1 - Nomenclature of gear failure modes ....................................................................................... 2
Table 2 - Failure modes that have subsurface origins ........................................................................... 44
Table 3 - Fracture classifications ............................................................................................................. 55
Table 4 - Differences between TIFF and subsurface initiated bending fatigue .................................... 74

Figures
Figure 1 - Moderate wear ....................................................................................................................... 3
Figure 2 - Severe wear .............................................................................................................................. 4
Figure 3 - SEM image - abrasion ........................................................................................................... 6
Figure 4 - Mild abrasion near the tip of a ground gear ............................................................................ 6
Figure 5 - Severe abrasion ..................................................................................................................... 7
Figure 6 - Severe abrasion, enlarged view of Figure 5 ........................................................................... 7
Figure 7 - Severe abrasion ..................................................................................................................... 7
Figure 8 - Severe polishing .................................................................................................................... 10
Figure 9 - Severe polishing .................................................................................................................... 10
Figure 10 - Extensive corrosion ............................................................................................................. 11
Figure 11 - Fretting corrosion .............................................................................................................. 12
Figure 12 - Scaling .................................................................................................................................. 14
Figure 13 - White layer flaking ............................................................................................................. 15
Figure 14 - Cavitation damage .............................................................................................................. 16
Figure 15 - Cavitation damage .............................................................................................................. 16
Figure 16 - SEM image - cavitation damage .......................................................................................... 17
Figure 17 - SEM image - cavitation damage .......................................................................................... 17
Figure 18 - Erosion of a high speed helical gear ................................................................................... 18
Figure 19 - Electric discharge damage due to a small electric current .................................................... 19
Figure 20 - Severe electric discharge damage due to an electric current of high intensity ...................... 19
Figure 21 - SEM image - typical electric discharge crater ..................................................................... 20
Figure 22 - SEM image - remelted metal and gas pockets near edge of crater ....................................... 20
Figure 23 - SEM image - electric discharge damage ............................................................................ 21
Figure 24 - Mild scuffing ....................................................................................................................... 22
Figure 25 - SEM image - scuffing damage showing rough, torn, and plastically deformed appearance .. 22
Figure 26 - SEM image - scuffing damage showing crater formed when welded material was torn from surface ................................................................................................................................................... 23
Figure 27 - Moderate scuffing .............................................................................................................. 23
Figure 28 - Severe scuffing .................................................................................................................... 24
Figure 29 - Severe scuffing of a low speed gear lubricated with grease ................................................. 24
Figure 30 - Severe indentations ............................................................................................................. 27
Figure 31 - Hot flow ................................................................................................................................ 28
Figure 32 - Plastic deformation by rolling ............................................................................................ 28
Figure 33 - Plastic deformation by tooth hammer .................................................................................... 29
Figure 34 - Rippling ................................................................................................................................ 29
Figure 89 - TIFF failure on an idler gear ..................................................................................................... 73
Figure 88 - EDS spectrum of figure 86 area 3 showing chemistry of the steel matrix ................................ 72
Figure 86 - BSE image of fracture surface showing scanned areas 1, 2, and 3 ........................................ 71
Figure 85 - Fracture surface of loose fragment showing nonmetallic inclusion .......................................... 71
Figure 82 - Broken tooth ends .................................................................................................................... 69
Figure 80 - Fatigue of several teeth that were loaded on both flanks ......................................................... 68
Figure 79 - Bending fatigue of two bevel pinion teeth ................................................................................. 67
Figure 75 - Two adjacent teeth on a helical pinion that failed by bending fatigue ...................................... 63
Figure 72 - Mixed mode fracture ................................................................................................................. 60
Figure 71 - SEM image of ductile fracture .................................................................................................. 59
Figure 70 - SEM image of intergranular brittle fracture ............................................................................... 57
Figure 69 - SEM image of transgranular brittle fracture .............................................................................. 56
Figure 68 - Brittle fracture ........................................................................................................................... 56
Figure 67 - Bending fatigue crack ............................................................................................................... 54
Figure 66 - Case/core separation ............................................................................................................... 53
Figure 65 - Case/core separation ................................................................................................................ 52
Figure 64 - Fracture surface of rim crack shown in Figure 63 .................................................................... 52
Figure 63 - Rim cracks in through hardened annulus gear ....................................................................... 51
Figure 62 - Rim crack................................................................................................................................. 49
Figure 61 - Grinding cracks with a crazed pattern ....................................................................................... 49
Figure 60 - Hardening cracks .................................................................................................................... 47
Figure 59 - Crack at a forging defect ........................................................................................................... 46
Figure 58 - Subcase fatigue ........................................................................................................................ 45
Figure 57 - Regularly distributed micropitting ............................................................................................ 41
Figure 56 - Detail of tooth surface showing micropitting ............................................................................. 40
Figure 55 - Detail of tooth surface showing micropitting at 1000X magnification ....................................... 40
Figure 54 - Micropitting on nitrided and ground spur gear .......................................................................... 40
Figure 53 - Micropitting on induction hardened spur gear with crowned teeth ........................................... 39
Figure 52 - Micropitting on misaligned carburized gear ............................................................................ 39
Figure 51 - Spall macropitting .................................................................................................................... 38
Figure 50 - Point-surface-origin macropitting ............................................................................................ 37
Figure 49 - Point-surface-origin macropitting on carburized helical driven pinion ..................................... 37
Figure 48 - Point-surface-origin macropitting on carburized helical gear at 3.0 × 10^7 cycles .................... 36
Figure 47 - Point-surface-origin macropitting on carburized helical gear at 1.5 × 10^7 cycles .................... 36
Figure 46 - Point-surface-origin macropitting ............................................................................................ 35
Figure 45 - Point-surface-origin macropitting ............................................................................................ 35
Figure 44 - Point-surface-origin macropitting on carburized helical pinion ............................................ 35
Figure 43 - Progressive macropitting ........................................................................................................ 34
Figure 42 - Nonprogressive macropitting .................................................................................................. 33
Figure 41 - SEM image - pitting damage caused by Hertzian fatigue, showing fatigue cracks near boundary of pit .......................................................................................................................... 33
Figure 40 - Cross section through a tooth flank showing how a pit develops below the surface ............... 32
Figure 39 - Tip-to-root interference .......................................................................................................... 32
Figure 38 - Burr ........................................................................................................................................ 31
Figure 37 - Ridging ..................................................................................................................................... 30
Figure 36 - Rippling ................................................................................................................................. 29
Figure 35 - Spall macropitting .................................................................................................................... 29

©AGMA 2014 – All rights reserved
Foreword

[The foreword, footnotes and annexes, if any, in this document are provided for informational purposes only and are not to be construed as a part of ANSI/AGMA 1010-F14, Appearance of Gear Teeth - Terminology of Wear and Failure.]

This standard provides a means to describe the appearance of gear teeth when they wear or fail. The study of gear tooth wear and failure has been hampered by the inability of two observers to describe the same phenomenon in terms that are adequate to assure uniform interpretation.

The term "gear failure" is subjective and a source of considerable disagreement. For example, a person observing gear teeth that have a bright, mirrorlike appearance may believe that the gears have “run-in” properly. However, another observer may believe that the gears have failed by polishing wear. Whether the gears should be considered failed or not depends on how much change from original condition is tolerable.

This standard provides a common language to describe gear wear and failure, and serves as a guide to uniformity and consistency in the use of that language. It describes the appearance of gear tooth failure modes and discusses their mechanisms, with the sole intent of facilitating identification of gear wear and failure. The purpose of the standard is to improve communication between equipment users and gear manufacturers for failure and wear analysis. Since there may be many different causes for each type of gear tooth wear or failure, it is not possible in the standard to identify a single cause for each type of wear or failure, nor to prescribe remedies.

AGMA Standard 110 was first published in 1943. A revised standard, AGMA 110.03, was published in 1979 with improved photographs and additional material. AGMA 110.04 was reaffirmed by the members in 1989.

ANSI/AGMA 1010-E95 was a revision of AGMA 110.04. It was approved by the AGMA Membership in March 9, 1995. It was approved as an American National Standard on December 13, 1995.

ANSI/AGMA 1010-F14 is a revision of ANSI/AGMA 1010-E95. It merges ANSI/AGMA 1010-E95 and AGMA 912-A04. New failure modes and additional photos were added and the content was reorganized. The description of failure mode morphology and mechanism was expanded, and methods to reduce the risk of a particular failure mode were added to the description of many of the failure modes.

The first draft of ANSI/AGMA 1010-F14 was made in August, 2010. It was approved by the AGMA membership in June, 2014. It was approved as an American National Standard on August 8, 2014.

Suggestions for improvement of this standard will be welcome. They may be submitted to tech@AGMA.org.
PERSONNEL of the AGMA Nomenclature Committee

Chairman: Dwight Smith ..................................... Cole Manufacturing Systems
Vice Chairman: J.M. Rinaldo............................... Atlas Copco Comptec, LLC

ACTIVE MEMBERS

J.B. Amendola, III................................................. Artec Machine Systems
K. Burris................................................................ Caterpillar, Inc.
R.L. Errichello..................................................... Geartech
O.A. LaBath......................................................... Gear Consulting Services of Cincinnati, LLC
M. Li...................................................................... Lufkin Industries, Inc.
P. Terry................................................................. P. Terry & Associates
American National Standard -

Appearance of Gear Teeth - Terminology of Wear and Failure

1 Scope
This standard provides nomenclature for general modes of gear tooth wear and failure. It classifies, identifies, and describes the most common types of failure and provides information that will, in many cases, enable the user to identify failure modes and evaluate the degree or change from original condition.

This standard is based on experience with steel gears; however, many of the failure modes discussed may apply to gears made from other materials.

The solution to many gear problems requires detailed investigation and analysis by specialists and is beyond the scope and intent of this standard.

This standard does not define “gear failure”. One observer’s “failure” is another observer’s “run-in”. There is no single definition of gear failure, since whether or not a gear has failed depends on the specific application.

The methods given for reducing the risk of a failure mode are specific to the failure mode considered, and implementation may sometimes worsen, or create other failure modes or unintended consequences. Therefore, it is imperative that any remedy be evaluated prior to implementation and thoroughly tested and evaluated after implementation.

NOTE: “gear” throughout the standard means gear or pinion unless the gear is specifically identified.

2 Normative references
The following documents contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions were valid. All publications are subject to revision, and the users of this standard are encouraged to investigate the possibility of applying the most recent editions of the publications listed:

AGMA 901-A92, A Rational Procedure for the Preliminary Design of Minimum Volume Gears
AGMA 923-B05, Metallurgical Specifications for Steel Gearing
ANSI/AGMA 1012-G05, Gear Nomenclature, Definitions of Terms with Symbols
ANSI/AGMA/AWEA 6006-A03, Standard for Design and Specification of Gearboxes for Wind Turbines
ANSI/AGMA 6011-I03, Specification for High Speed Helical Gear Units
ANSI/AGMA 6013-A06, Standard for Industrial Enclosed Gear Drives
ANSI/AGMA 9005-E02, Industrial Gear Lubrication
ISO 14104, Gears - Surface temper etch inspection after grinding

3 Definitions

3.1 Definitions
The terms used in this standard, wherever applicable, conform to the definitions given in ANSI/AGMA 1012-G05 and AGMA 923-B05.

NOTE: The symbols and definitions used in this standard may differ from other AGMA Standards. The user should not assume that familiar symbols can be used without a careful study of these definitions.