



American
Gear Manufacturers
Association

Technical Resources

ANSI/AGMA 6032-B13
(Revision of ANSI/AGMA 6032-A94)

American National Standard

Standard for Marine Gear Units: Rating and Application for Spur and Helical Gear Teeth

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ABSTRACT

This document considers rating practices for marine main propulsion, power take-off and auxiliary propulsion service. Practical suggestions are included for various factors. Allowable stress numbers for materials of this standard, as covered in ANSI/AGMA 6033-C08, are included.

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Contents

Foreword	vii
1 Scope	1
1.1 Application	1
1.2 Intended use	1
1.3 Exceptions	1
1.4 Marine gear rating parameter sheet	2
1.5 Alternative ratings	2
2 Normative references	2
3 Terms and symbols	2
3.1 Terms	2
3.2 Symbols	3
4 Application	4
4.1 System responsibility	4
4.2 Manufacturing tolerances	4
4.3 Other considerations	4
4.3.1 Misalignment and deflection of foundations	5
4.3.2 Installation and alignment	5
4.3.3 Deflection due to external forces	5
4.3.4 Metallurgy	5
4.3.5 Residual stress	5
4.3.6 Lubrication	5
4.3.7 System dynamics	5
4.3.8 Corrosion	6
4.3.9 Cold temperature operation	6
4.3.10 Pitch and roll considerations	6
5 Criteria for tooth capacity	7
5.1 Relationship of pitting resistance and bending strength ratings	7
5.2 Pitting resistance	7
5.2.1 Intent of pitting resistance formula	7
5.3 Surface conditions not covered by this standard	7
5.4 Bending strength	7
5.4.1 Intent of bending strength formula	7
6 Rating formulas	8
6.1 Allowable transmitted power, P_a	8
6.2 Allowable transmitted power for pitting resistance, P_{ac}	8
6.2.1 Dynamic factor, K_v	8
6.2.2 Load distribution factor, K_m	9
6.2.3 Stress cycle factor, Z_N	9
6.2.4 Hardness ratio factor, C_H	9
6.3 Allowable transmitted power for bending strength, P_{at}	10
6.3.1 Stress cycle factor, Y_N	10
6.3.2 Rim thickness factor, K_B	10
6.4 Allowable stress numbers for pitting resistance and bending strength	10
6.5 Reverse loading	10
6.5.1 Reverse bending	10
6.5.2 Normal reversing operation	11

7	Tangential load, W_t	11
7.1	Double helical gear loads.....	11
8	Overload factor, K_o	11
8.1	Ice service	12
9	Safety factors, S_H , S_F	12
10	Allowable stress numbers, s_{ac} and s_{at}	12
10.1	Stress numbers	12
10.2	Guide for case depth of surface hardened gears.....	12
10.2.1	Carburized gears.....	12
10.2.2	Induction hardened gears	14
10.2.3	Nitrided gears	14
10.3	Reverse tooth loading	15
11	Stress cycle factors, Z_N and Y_N	15
11.1	Recommended life	15
11.2	Multiple power levels.....	15
12	Service factors, C_{SF} , K_{SF}	15
13	Non-uniform loads.....	16
13.1	Momentary overload	16
13.1.1	Yield strength	16
13.2	Intermittent engine ratings.....	17
13.3	Duty cycle.....	17
14	Manufacture	17
14.1	Accuracy.....	17
14.2	Finishing operations	17
14.3	Balance	18
14.4	Backlash checks.....	18
14.5	Contact checks - installation and post sea trial.....	18
15	Bearings.....	18
15.1	Radial bearings	18
15.1.1	Hydrodynamic oil film journal bearings	18
15.1.2	Rolling contact bearings.....	19
15.2	Thrust bearings	21
15.2.1	Hydrodynamic oil film thrust bearings	21
15.2.2	Rolling contact thrust bearings.....	22
15.2.3	Propeller thrust loads	22
15.2.4	Universal joints.....	22
16	Lubrication	22
16.1	Applicability	22
16.1.1	Ambient temperature.....	22
16.1.2	Oil sump temperature.....	22
16.1.3	Mounting position	22
16.2	Lubricant viscosity	23
16.2.1	Film thickness and wear.....	23
16.2.2	Scuffing (scoring) and wear	23

16.3	Lubrication recommendations	23
16.4	Cold temperature starting.....	23
16.4.1	Low temperature conditions	23
16.4.2	Sump heaters	23
16.5	Lubricants	23
16.5.1	Rust and oxidation inhibited gear oils	23
16.5.2	Extreme pressure lubricants	23
16.5.3	Synthetic gear lubricants.....	23
16.6	Lubricant cleanliness.....	24
16.7	Lubrication system	24
16.7.1	Lubrication system components.....	24
16.7.2	Additional equipment.....	24
17	Clutches	24
17.1	Pneumatic clutches	25
17.2	Hydraulic clutches	25
17.3	Mechanical synchronous clutches	25
17.4	Torsional damping characteristics.....	25
17.5	Selection.....	25
17.5.1	Static load conditions	25
17.5.2	Dynamic loading.....	25
17.5.3	Selection criteria.....	25
17.6	Balancing.....	25
17.7	Mechanical “come home” feature.....	26
17.8	Clutch control system.....	26
17.8.1	Control system timing.....	26
17.8.2	Pneumatic clutch controls	26
17.8.3	Hydraulic clutch controls	26
17.8.4	Control system features	26
18	Shafting.....	27
18.1	Shaft outside diameter, dos	27
18.1.1	Solid shaft with bending and torsion loads.....	27
18.1.2	Hollow shaft with bending and torsion loads.....	28
18.1.3	Press fitted shafts.....	28
18.2	Allowable stress	28
18.2.1	Basic stress limits.....	28
18.2.2	Shaft fatigue limit, S_f	28
18.2.3	Shaft fatigue limit modification factor, k	29
18.2.4	Shaft material reliability factor, k_c	29
18.2.5	Shaft temperature factor, k_d	29
18.2.6	Shaft life factor, k_e	29
18.2.7	Shaft miscellaneous effects factor, k_g	30

18.3	Shaft deflections.....	30
19	System vibration	30
19.1	Torsional vibrations	30
19.2	Lateral vibrations	32
19.3	Axial vibrations	32
19.4	Modal vibrations	32

Annexes

Annex A	Marine gear rating parameter sheet	33
Annex B	Engine power and operating profile data	35
Annex C	System component and dynamic analysis data	36
Annex D	Alternative rating methods	38
Annex E	Derating factor for reversing bull gear teeth.....	39
Annex F	Bibliography	44

Tables

Table 1	- Symbols used in equations.....	3
Table 2	- Design angles of inclination	6
Table 3	- Overload factor ^{1), 2)} , K_o	11
Table 4	- Allowable contact stress number, s_{ac} , for steel gears	13
Table 5	- Allowable bending stress number, s_{at} , for steel gears	14
Table 6	- Recommended life of gear units	15
Table 7	- Service factors, C_{SF} , K_{SF}	15
Table 8	- Typical surface finish ranges	17
Table 9	- Recommended design limits for fluid film radial bearings	18
Table 10	- Recommended minimum L_{10} bearing life	20
Table 11	- Recommended lubricant cleanliness	24
Table 12	- Shaft material reliability factor, k_c	29
Table 13	- Permissible vibratory pinion torque.....	31

Figures

Figure 1	- Tooth by tooth hardening pattern produced by a male, type A, inductor	13
Figure 2	- Shaft design for press fitted gear.....	28

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 6032-B13, *Standard for Marine Gear Units: Rating and Application for Spur and Helical Gear Teeth*.]

This standard presents the methodology for determining the ratings of marine reduction and reversing gear systems driven by internal combustion engines, electric motors, and steam or gas turbines. It does not cover separate power generation drives, pump set drives, conveyor drives, deck machinery or the design and application of epicyclic drives. It supersedes ANSI/AGMA 6032-A94.

This standard interprets ANSI/AGMA 2001-D04 for use by the marine industry considering the successful practice of marine gear manufacturers and the incorporation of its predecessor standards into the American Bureau of Shipping (ABS) Rules for Building and Classing Steel Vessels, as they existed, prior to 2000. The ABS Rules were based on AGMA rating Standards 211 and 221 as published in the early 1970's.

The previous version of this standard was based on ANSI/AGMA 2001-A88 and, except where indicated, all changes incorporated in ANSI/AGMA 2001, up to and including the present version, are captured herein. These changes include, but are not limited to, moderate revisions to the allowable stresses, s_{ac} and s_{at} , of some materials and a redefining of the dynamic factor, K_v .

Changes of note to this standard include:

- The separation of the standard into metric and U.S. unit editions;
- The changing of the title to be more indicative of the content of the standard;
- The removal of the basic rating equations which are included in ANSI/AGMA 2001-D04;
- The removal of references relating to rating methods based on K factor and unit load;
- The replacement of the application factor, K_a , with an overload factor, K_o , and service factors, C_{SF} and K_{SF} to be more consistent with current practice in the marine industry;
- The incorporation of the effect of the increased safety factors, historically used for capital ships, into the service factors;
- The specifying of gear rating in terms of allowable transmitted power rather than working stress as was the practice in the previous version;
- The addition of a new annex which addresses derating of the bull gear for astern operation of the vessel.

The overall effect of these changes is a reduction of the allowable transmitted power, for pitting resistance and bending strength, of the gearset. This reduction is essentially due to the inclusion of the service factors, C_{SF} and K_{SF} .

The first draft of ANSI/AGMA 6032-B13 was made in May, 2008. It was approved by the AGMA membership in October, 2013. It was approved as an American National Standard on September 23, 2013.

Suggestions for improvement of this standard will be welcome. They may be submitted to tech@agma.org.

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American National Standard -

Standard for Marine Gear Units: Rating and Application for Spur and Helical Gear Teeth

1 Scope

1.1 Application

This standard is applicable to marine reduction and reversing gears, including those used in capital ships, as follows:

- marine propulsion reduction gears driven by internal combustion engines or electric motors from 1,500 to 20,000 horsepower per prime mover, with rotor speeds not exceeding 3600 rpm;
- marine propulsion reduction gears driven by steam or gas turbines from 1,500 to 30,000 horsepower per prime mover;
- power take-off (PTO) gearing that is integral to the propulsion unit;
- auxiliary propulsion gears;
- combinations of drives listed above.

Although the above referenced power requirements are based on actual operating experience, the design criteria in this standard are also applicable to larger power prime movers. As with any new application, caution should be exercised when extrapolating requirements outside of the current experience range.

In this standard, capital ships are vessels characterized by larger tonnage, higher horsepower, or deep water operation.

The fundamental rating formulas are applicable for rating the pitting resistance and bending strength of external spur, helical, or double helical involute gear teeth. The formulas evaluate gear tooth capacity as influenced by the major factors which affect gear tooth pitting and gear tooth fracture.

This standard also addresses bearings, clutches and controls, lubricating systems, shaft stresses, balance and system vibrations. Gear blank design is not addressed.

1.2 Intended use

This standard provides a method by which different gear designs can be compared. It is intended for use by the experienced gear designer capable of selecting reasonable values for the various factors, based on their knowledge of performance of similar designs and the effects of such items as lubrication, deflection, manufacturing tolerances, metallurgy, residual stress and system dynamics.

The majority of marine gears are of helical or double helical tooth design. Spur gear tooth designs are not generally used except for power take-off drives and reversing sections of marine gear units.

This standard is not intended to assure performance of assembled gear drive systems, and is not intended for use by the engineering public at large.

1.3 Exceptions

This standard does not cover:

- separate power generation drives;
- pump set drives;
- conveyor drives;

- deck machinery;
- epicyclic drives.

The determination of gear mesh efficiency or overall drive efficiency is beyond the scope of this standard.

This standard does not cover the rating of gear drives due to the wear or scuffing (scoring) of gear teeth or components. See AGMA 925-A03 for a consideration of scuffing.

1.4 Marine gear rating parameter sheet

A marine gear rating parameter sheet is included in Annex A to assist in determining the actual applicability of a gear for its intended service.

1.5 Alternative ratings

It is recognized that marine units may be rated in different manners for the same service. Annex D provides additional information on alternative rating methods applied by marine classification societies.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this American National Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this American National Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below.

AGMA 908- B89, *Information Sheet - Geometry Factors for Determining the Pitting Resistance and Bending Strength of Spur, Helical and Herringbone Gear Teeth*

AGMA 923-B05, *Metallurgical Specifications for Steel Gearing*

AGMA 925-A03, *Effect of Lubrication on Gear Surface Distress*

AGMA 927-A01, *Load Distribution Factors - Analytical Methods for Cylindrical Gears*

AGMA 938-A05, *Shot Peening of Gears*

ANSI/AGMA 1010-E95, *Appearance of Gear Teeth - Terminology of Wear and Failure*

ANSI/AGMA 1012-G05, *Gear Nomenclature, Definitions of Terms with Symbols*

ANSI/AGMA 2001-D04, *Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth*

ANSI/AGMA 2015-1-A01, *Accuracy Classification System - Tangential Measurements for Cylindrical Gears*

ANSI/AGMA 2015-2-A06, *Accuracy Classification System - Radial Measurements for Cylindrical Gears*

ANSI/AGMA 6001-E08, *Design and Selection of Components for Enclosed Gear Drives*

ANSI/AGMA 6033-C08, *Materials for Marine Propulsion Gearing*

ANSI/AGMA ISO 6336-6-A08, *Calculation of Load Capacity of Spur and Helical Gears - Part 6: Calculation of Service Life Under Variable Load*

ANSI/AGMA 9005-E02, *Industrial Gear Lubrication*

ISO 4406:1999, *Hydraulic fluid power - Fluids - Method of coding the level of contamination by solid particles*

ISO 1940-1:2003, *Mechanical vibration - balance quality requirements for rotors in a constant (rigid) state - Part 1: specification and verification of balance tolerances*

3 Terms and symbols

3.1 Terms

The terms used, wherever applicable, conform to ANSI/AGMA 1012-G05.

3.2 Symbols

The symbols used in this standard are shown in Table 1.

NOTE: The terms and symbols used in this standard may differ from those used in other AGMA Standards. Users of this standard should satisfy themselves that they are using these terms and symbols in the manner indicated herein.

Table 1 - Symbols used in equations

Symbol	Description	Units	First used
A_v	Transmission accuracy level number	--	6.2.1
C_f	Surface condition factor for pitting resistance	--	6.2
C_H	Hardness ratio factor for pitting resistance	--	6.2.4
C_{SF}	Service factor for pitting resistance	--	Table 7
d_{is}	Shaft inside diameter	in	Eq 6
d_{os}	Shaft outside diameter	in	Eq 3
F	Net face width of narrowest member	in	Eq 2
F_s	Shaft factor of safety	--	Eq 3
J	Geometry factor for bending strength	--	Eq 2
K_B	Rim thickness factor	--	6.3.2
K_b	Theoretical stress concentration factor in bending	--	Eq 4
K_f	Stress correction factor	--	Eq 2
K_{fb}	Fatigue stress concentration factor in bending	--	Eq 3
K_{ft}	Fatigue stress concentration factor in torsion	--	Eq 3
K_m	Load distribution factor	--	6.2.2
K_{my}	Load distribution factor under maximum overload condition	--	Eq 2
K_R	Reliability factor	--	6.2
K_o	Overload factor	--	4.3.7
K_s	Size factor	--	6.2
K_{SF}	Service factor for bending strength	--	Table 7
K_T	Temperature factor	--	6.2
K_{ts}	Theoretical stress concentration factor in torsion	--	Eq 5
K_v	Dynamic factor	--	6.2.1
k	Shaft fatigue limit modification factor	--	Eq 7
k_a	Shaft surface finish factor	--	Eq 9
k_b	Shaft size factor	--	Eq 9
k_c	Shaft material reliability factor	--	Eq 9
k_d	Shaft temperature factor	--	Eq 9
k_e	Shaft life factor	--	Eq 9
k_g	Shaft miscellaneous factor	--	Eq 9
M_a	Alternating reverse bending moment	lb in	Eq 3
M_m	Steady state shaft bending moment	lb in	Eq 3
P_a	Allowable transmitted power for gear set	hp	Eq 1
P_{ac}	Allowable transmitted power for pitting resistance	hp	Eq 1
P_{at}	Allowable transmitted power for bending strength	hp	Eq 1
P_d	Transverse diametral pitch at generating pitch diameter	in ⁻¹	Eq 2

Symbol	Description	Units	First used
q_b	Notch sensitivity factor in bending	- -	Eq 4
q_t	Notch sensitivity factor in torsion	- -	Eq 5
S_F	Safety factor for bending	- -	Clause 9
S_f	Shaft endurance limit in bending	lb/in ²	Eq 3
S_{fe}	Shaft endurance limit of polished, unnotched test specimen in reverse bending	lb/in ²	Eq 7
S_H	Safety factor for pitting	- -	Clause 9
S_u	Shaft ultimate tensile strength	lb/in ²	Eq 8
S_Y	Safety factor for tooth yield stress	- -	Eq 2
S_y	Shaft tensile yield strength	lb/in ²	Eq 3
s_{ac}	Allowable contact stress number	lb/in ²	Table 4
s_{at}	Allowable bending stress number	lb/in ²	Table 5
s_{ay}	Allowable yield stress number	lb/in ²	Eq 2
T_a	Alternating shaft torque	lb in	Eq 3
T_m	Mean pinion torque at operating speed	lb in	Table 13
T_{ms}	Mean shaft torque	lb in	Eq 3
T_R	Rated pinion torque at operating speed	lb in	Table 13
T_v	Permissible vibratory component of torque at operating speed	lb in	Table 13
W_t	Tangential load	lb	Clause 7
W_{tmax}	Maximum tangential load	lb	Eq 2
Y_N	Stress cycle factor for bending strength	- -	6.3.1
Z_N	Stress cycle factor for pitting resistance	- -	6.2.3

4 Application

4.1 System responsibility

The successful performance of a marine reduction gear requires a thorough evaluation of the system in which it operates. The complete system consists of all components from the prime mover to the propeller/waterjet, including gears, shafts, bearings, clutches and any relevant control systems. Successful gear applications take into consideration the complete propulsion system's design, manufacture, support, alignment, lubrication and operation. In addition, the system should be free from harmful vibratory forces in the operating speed ranges. Clear designation of responsibility and clear communication between the owner, shipbuilder, designer, and machinery supplier are necessary.

The party having contractual responsibility for the analysis of the system should be clearly identified in the specification, contract or purchase order. Substantial costs are involved in a system analysis. All parties supplying components to the system have the responsibility to furnish correct and accurate data, in a timely manner, so that the analysis is meaningful.

4.2 Manufacturing tolerances

Rating factors should be evaluated considering the expected process variations of component parts.

4.3 Other considerations

In addition to the factors considered in this standard which influence pitting resistance and bending strength, other interrelated factors can affect overall transmission performance. The following are particularly significant.

4.3.1 Misalignment and deflection of foundations

Many gear systems depend on external supports such as machinery foundations to maintain alignment of the gear mesh. If these supports are not properly aligned or deviate from specified tolerances during operation through elastic or thermal deflection, reduction gear performance may be adversely affected.

The rating factors in this standard assume proper support of the gear unit. If proper support is not provided, these factors are not applicable.

4.3.2 Installation and alignment

The gear ratings, shaft stresses, bearing loads, and bearing lives established in this standard require proper unit installation and alignment. Additional information may be found in [1].

4.3.3 Deflection due to external forces

Deflection of the gear housing, shafts, and bearings due to external overhung loads and thrust forces may influence tooth contact across the mesh, bearing alignment and bearing clearances. The gear unit should be designed to accommodate these forces.

4.3.4 Metallurgy

The allowable stress numbers, s_{ac} and s_{at} , included herein are a function of melting, casting, forging and heat treating practice. Hardness, tensile strength, microstructure and cleanliness are some of the criteria for determining allowable stress numbers.

Variations in microstructure account for some variation in gear capacity. Higher levels of cleanliness and better metallurgical control permit the use of higher allowable stress numbers. Conversely, lower quality levels require the use of lower allowable stress numbers.

Material recommendations may be found in ANSI/AGMA 6033-C08.

4.3.5 Residual stress

Any material having a case-core relationship is likely to have residual stresses. If properly managed, these stresses will be compressive and will enhance the bending strength of the gear teeth. Shot peening, case carburizing, nitriding, and induction hardening are common methods of inducing compressive pre-stress into the surface of the gear teeth.

Grinding the tooth surface after heat treatment may reduce the residual compressive stresses. Grinding the tooth surface and root fillet area may introduce tensile stresses, stress risers, and possibly cracks in these areas if not done properly. Care must be taken to avoid excessive reduction in hardness, case depth and changes in microstructure during the grinding process.

Shot peening of root fillets is often performed to improve the presence of residual compressive stresses. Care must be taken to avoid unnecessarily reducing or eliminating such compressive stresses by subsequent machining, grinding, or thermal treatment. See AGMA 938-A05 for additional considerations pertaining to shot peening.

4.3.6 Lubrication

The ratings determined by the formulas included herein are valid only when the gear teeth are operated with a lubricant of proper viscosity for the load, surface finish, temperature, and pitch line velocity. This standard does not address scuffing or other forms of lubrication related wear. These phenomena should be evaluated and reference is made to AGMA 925-A03.

For further details on marine reduction gear lubrication see clause 16.

4.3.7 System dynamics

The dynamic response of the system results in additional loads to the gear teeth and other components. The overload factor, K_o , is intended to account for those additional tooth loads due to dynamic and steady state operating characteristics of the driving and driven equipment.

Torsional, axial and transverse vibrations of the system must be considered for satisfactory performance of marine gears. The natural frequencies and amplitudes of vibration depend on the mass, elasticity and damping for the total power train. Operating roughness such as the firing of the engine cylinders, propeller blades passing through a varying flow field, damaged or fouled propellers, rotational unbalance and gear tooth meshing variations produce pulsating excitation forces which may sustain vibrations of the system. If the value of the excitation frequency is near the value of a natural frequency, resonance will occur, which may cause overloads several times higher than the nominal load on the system.

A minimum margin of 10% is required between operating and critical speeds.

The system analysis must include the total system of driver, gearbox, driven equipment, couplings, mounting conditions, and the sources of excitation. Natural frequencies, mode shapes, and the dynamic response amplitudes should be calculated.

The steady state component of propeller/waterjet loading may vary due to such things as hull fouling, draft change and shallow bottoms, even though the propeller/impeller speed is maintained constant. This additional loading should be supplied by the shipyard, naval architect or purchaser.

The party with contractual responsibility for the system analysis, see 4.1, shall obtain data from the component manufacturers to define the mass, elasticity, damping and excitation characteristics of the system. Annex C indicates the type of data required of each component manufacturer.

4.3.8 Corrosion

Corrosion of gear unit components and of the gear tooth surfaces can have a significant detrimental effect on the life and pitting resistance of the teeth and bearings. Operational procedures such as dehumidification or lube oil centrifuging should be considered to minimize corrosion. Quantification of the effect of corrosion on gear teeth is beyond the scope of this standard.

4.3.9 Cold temperature operation

If gears are to be operated below 32°F, special care must be given to select materials which will have adequate impact properties at the operating temperature. Consideration should be given to:

- low temperature Charpy specification;
- fracture appearance transition or nil ductility temperature specification;
- reduction of carbon content in base material to less than 0.4 percent carbon;
- the use of higher nickel alloy steels.

In these instances, gear unit preheating should be considered.

4.3.10 Pitch and roll considerations

The propulsion machinery shall be designed to withstand angles of inclination as shown in Table 2.

Table 2 - Design angles of inclination

	Angle of inclination, degrees ^{1), 2)}			
	Athwartship		Fore-and-aft	
Installations, components	Static	Dynamic	Static	Dynamic
Propulsion and auxiliary machinery	15	22.5	5	7.5
NOTES: ¹⁾ Athwartship and fore-and-aft inclinations may occur simultaneously. ²⁾ Where the length of the vessel exceeds 328 ft, the fore-and-aft static angle of inclination may be taken as 1640/L degrees, where L is the length of the vessel in feet. [2]				

5 Criteria for tooth capacity

5.1 Relationship of pitting resistance and bending strength ratings

Gear tooth capacity is based on pitting resistance and bending strength ratings. Pitting resistance is related to the Hertzian contact (compressive) stresses between two cylinders which are proportional to the square root of the applied tooth load. Bending strength is related to the bending (tensile) stress in a cantilever plate which is directly proportional to the applied tooth load. The difference in the nature of the stresses induced in the tooth surfaces and at the tooth root fillets is reflected in a corresponding difference in the allowable limits for the contact and bending stress numbers for identical materials and load intensities.

The analysis of the load and stress modifying factors is similar in each case, so many of these factors have identical numerical values.

The term “gear failure” is itself subjective and a source of considerable disagreement. One observer’s failure may be another observer’s wearing-in. A more complete discussion on gear failure can be found in ANSI/AGMA 1010-E95.

5.2 Pitting resistance

The pitting of gear teeth is a fatigue phenomenon. Initial pitting and progressive pitting (sometimes called destructive pitting) are illustrated and discussed in ANSI/AGMA 1010-E95.

Initial pitting of through hardened gears is characterized by small pits which do not extend over the entire face width or profile height of the affected teeth. The definition of acceptable initial pitting varies widely with gear application. Initial pitting occurs in localized, overstressed areas. It tends to redistribute the load by progressively removing high contact spots. Generally, when the stresses caused by the localized load have been reduced to acceptable levels, the pitting stops. If it continues to progress, it is not initial pitting. In general marine practice, most initial pitting of through hardened gears is not deemed as serious.

Pitting of surface hardened gears is generally not acceptable.

5.2.1 Intent of pitting resistance formula

The intent of the pitting resistance formula is to determine the intensity of the load which can be transmitted for the design life of the teeth without causing progressive pitting.

The ratings for pitting resistance are based on the formulas developed by Hertz for contact pressure between two curved surfaces, modified for the effects of load sharing between adjacent teeth.

5.3 Surface conditions not covered by this standard

Micropitting, electric discharge pitting, wear and scuffing are not covered by this standard. They are discussed in ANSI/AGMA 1010-E95.

5.4 Bending strength

The bending strength of gear teeth is a measure of the resistance to fatigue cracking at the tooth root fillet. Typical cracks and fractures are illustrated in ANSI/AGMA 1010-E95.

The basic theory employed in this analysis assumes the gear tooth to be rigidly fixed at its base. If the rim supporting the gear tooth is thin relative to the size of the tooth and the gear pitch diameter, the location of the critical stress may be through the gear rim, rather than at the tooth root fillet, see 6.3.2.

5.4.1 Intent of bending strength formula

The intent of the bending strength formula is to determine the intensity of the load which can be transmitted for the design life of the teeth without causing tooth root fillet cracking or fracture.

Occasionally, wear, surface fatigue, or plastic flow may limit bending strength due to stress concentration around large, sharp cornered pits or wear steps on the tooth surface.

The strength ratings determined by this standard are based on plate theory modified to consider:

- compressive stress at the tooth root fillets caused by the radial component of tooth loading;
- non-uniform moment distribution resulting from the oblique lines of contact on helical teeth;
- stress concentrations at the tooth root fillets;
- load sharing between adjacent teeth.

6 Rating formulas

The pitting resistance power rating and the bending strength power rating for each mesh in the reduction gear must be calculated, and the lowest value obtained shall be used as the power rating of the unit. It is permissible to use more conservative values.

All variables described in this standard and used in these rating formulas must be considered, and should any variable(s) be ignored or improperly used, the gear tooth rating will be in error.

6.1 Allowable transmitted power, P_a

The allowable transmitted power for the gear set, P_a , is determined by:

$$P_a = \text{the lesser of } \frac{P_{ac}}{C_{SF}} \text{ and } \frac{P_{at}}{K_{SF}} \quad (1)$$

where

P_{ac} is the allowable transmitted power for pitting resistance, see 6.2 and equation A.1;

C_{SF} is the service factor for pitting resistance, see clause 12;

P_{at} is the allowable transmitted power for bending strength, see 6.3 and equation A.2;

K_{SF} is the service factor for bending strength, see clause 12.

CAUTION: Both pinion and gear teeth must be checked to account for the differences in material properties, geometry factors, and the number of cycles under load. Therefore, the power rating should be based on the lowest values of the expressions for each of the mating gears.

6.2 Allowable transmitted power for pitting resistance, P_{ac}

The pitting resistance power rating, P_{ac} , shall be determined by the rating methods and formulas of ANSI/AGMA 2001-D04 using specific values and procedures for the following factors:

$K_R = 1.0$, the reliability factor;

$K_S = 1.0$, the size factor;

$K_T = 1.0$, the temperature factor;

$C_f = 1.0$, the surface condition factor;

K_v is the dynamic factor, see 6.2.1;

K_m is the load distribution factor, see 6.2.2;

Z_N is the stress cycle factor, see 6.2.3;

C_H is the hardness ratio factor, see 6.2.4;

K_o is the overload factor, see clause 8;

S_H is the safety factor, see clause 9.

6.2.1 Dynamic factor, K_v

The dynamic factor, K_v , accounts for internally generated tooth loads which are induced by non-conjugate meshing action of the gear teeth.

K_v shall be determined by clause 8 of ANSI/AGMA 2001-D04, with the exception that values of K_v shall not be based on a transmission accuracy level number less than $A_v = 6$.

The transmission accuracy level number, A_v , shall be based upon the quality level of the gearing produced. In the absence of a known specific quality level, the curve for $A_v = 9$ shall be used.