Application Analysis

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Question: I have heard the terms "safety factor," "service factor," and "application factor" used in discussing gear design. What are these factors and how do they differ from one another? Why are they important?

Bill Bradley & Don McVittie reply:

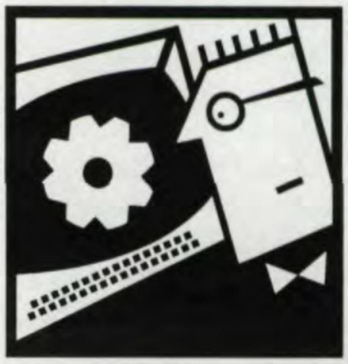
In any gear design, it is critical to make allowances for unknown variables in materials, machining tolerances, loading, etc. Various terms (factor of safety, service factor, and application factor) are used in the gear industry to describe this important concept. These terms are among the many formula variables (influence factors) which are used for determining the calculated load capacity of gears produced for various designs, manufacturing methods, and uses. Many of these factors have been empirically developed from accumulated experience. Therefore, it is critical that they be used in the manner originally intended. The influence factors are normally used as modifiers to either a calculated stress from part configuration and applied load, or to an allowable stress number based on material properties. The gear designer can then compare the modified calculated stress to the modified allowable stress number for a specific design, to determine suitability for a given application.

The gear designer, manufacturer, buyer, and user must all have a clear understanding of the meaning and implications of these terms when comparing gear capacity using different standards. The following definitions are given to explain the difference between these terms as applied to gearing.

Factor of Safety

The term "factor of safety" or "safety factor" has historically been used by designers and engineers to describe a general derating factor for limiting the design stress in proportion to the material strength. A factor of safety accounts for uncertainties in design analysis accuracy, material characteristics, and manufacturing quality.

When using a factor of safety, one must also consider the risk to human safety and the economic consequences of failure or machine "down-time." The greater the uncertainties or consequences of these considerations, the higher the factor of safety should be. As these items become known with more certainty, the value of the influence factors can be more accurately determined. For example, an automobile transmission which is subjected to full-size, full-load prototype testing and rigorous quality control of dimensions, materials, and processes during manufacture, could have a more precise factor of safety than a



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Gear testing, field experience, and material analysis are among the ways one can obtain more knowledge for design. As your design practices become more comprehensive, some influence factors can be removed from the unknown area of "factor of safety" and introduced as predictable portions of the design method. The AGMA material reliability factor, C_R, is an example.

Factor of safety has also been used to account for uncertainties in "applied loading" or unknown overloads. In gear design, however, service factors or application factors have been used to cover this uncertainty.

Application Factor

An application factor is used to make allowance for any externally applied overloads (loads in excess of the nominal transmitted load). Application factors are established only with considerable field experience with a specific design. In determining the application factor, consider the fact that systems develop momentary peak torques appreciably greater than those determined by the nominal ratings of the prime mover or driven equipment. Many possible sources of overloads, such as system vibrations, acceleration torques, over-speeds, variations in system operation, split-path load sharing among multiple prime movers, and changes in process load conditions, also must be considered.

Service Factor

A service factor is traditionally applied as a multiplier of the nominal application load to determine catalog selections of pre-designed gear units. In AGMA gear rating, the service factor has been used to include the combined effects of the required life cycles, material reliability, and application factors in an empirically determined single influence factor. The specific mathematical contribution of each of these items has not been satisfactorily established. In addition, the term "service factor" has been used when including human safety or economic risk, which has developed confusion between the terms factor of safety, application factor, and service factor.

To avoid confusion, it is recommended that the application factor be used as defined - for external variability in applied loading. A factor of safety should be applied where there is human risk, economic risk, or remaining uncertainties due to design, material, or manufacturing quality variation.

When an application factor is used in place of a service factor and a long service life is desired, give consideration to the allowable stress levels. In the absence of specific knowledge, a life factor of 0.85 (multiplier for service capacity) for pitting resistance and 0.80 for bending strength should be considered.

Apply a service factor ONLY to a gear assembly, typically to a catalog drive rating, and then only in the absence of more specific application load data. Furthermore a service factor should be used only with the calculation method used at the time this experience factor was developed. It should not be used with other gear-calculation methods, unless sufficient knowledge and experience exists to make a satisfactory conversion.

Other Considerations

Important considerations for your design analysis of gear-drive systems which are related to factor of safety, application factor, and service factor selection include:

Test and field experience. The proper selection of application factors and factors of safety for power transmission systems often are not given enough attention. Without complete testing and field experience on each specific design, the application of gears has many unknowns. Therefore, conservative selection of all gear capacity calculation influence factors is recommended unless operating experience of an identical design is known.

Thermal Rating. The thermal power rating of a gear system is defined as the power that the unit will transmit continuously without exceeding established temperature limits. This important consideration is necessary to maintain proper lubrication. Excessive temperatures are detrimental to the lubrication of gear teeth and to elastomeric seals, such that the system may not be able to transmit the rated power without excessive wear and failure.

Non-Gear Components. Every component of a gear unit must allow for the proper transmission of power, considering both internal and any external loading. Components, such as housing supports, shafting, keys, splines, bearings, and fasteners (bolts, nuts, etc.), must be designed and manufactured to maintain the gears in proper position as well as transmit the required power.

Gear Quality. The term "quality" can have a number of meanings. In reference to gear manufacture, it is generally used to classify the tolerances applied to the gear tooth geom-

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etry and the quality of gear materials and heat treatment. Unless the appropriate gear quality level is used to calculate the power rating of a gear system and that quality level is, in fact, duplicated or exceeded in manufacturing, the unit produced may not have the desired life.

Variation of Manufacture. In addition to gears, the metallurgical quality of all stressed parts and the geometrical accuracy of all other components of the drive must exceed the values assumed in the design calculations and test units.

Some standards do not mention these topics or do not cover them thoroughly. It is important to know that factors contained within AGMA standards, such as service factor, should not be abstracted and applied to other standard methods of calculating gear capacity. Mixing factors from different standards can result in an inadequate design.

Summary

When designing and rating gearing, there is a need to use factors of safety, service factors, and application factors. There must be a thorough knowledge of these terms for proper design. As the variables in design, materials, manufacturing, and loading become better controlled, the factor of safety can be reduced; the application factors will represent actual loading or be replaced by a load spectrum analysis, such as Miner's Rule; and service factors may be replaced with factors of safety, application factors, life factors, and reliability factors.

One must clearly understand that the gear design or analysis must account for these uncertainties, based on experience. That is the primary responsibility of the gear engineer. ■

Editor's Note: *This information is based on a presentation made at the International Federation for the Theory of Machines and Mechanisms gear meeting in Hiroshima, Japan, in November, 1991. It also appeared in the AGMA News Digest, Nov/Dec, 1992. Reprinted with permission.*