INFLUENCE OF TOOTH GEOMETRY ON THE STRENGTH OF PLASTIC SPUR GEARS.

First Author's Name: JorgeLaureano Moya Rodríguez
Institution and address: Universidad Central "Marta Abreu" de Las Villas. Santa Clara. Villa Clara. Cuba.
e-mail: jorgemr@fim.uclv.edu.cu

Second Author's Name: José Alberto Velázquez Pérez
Institution and address: Universidad Veracruzana, sede Xalapa. Xalapa, Veracuz, México.
e-mail: javp521222@hotmail.com

Other authors: Rafael Goytisolo Espinosa
Institution and address: Universidad "Carlos Rafael Rodríguez" de Cienfuegos. Cienfuegos. Cuba.
e-mail: ragoyti@fmec.ucf.edu.cu.

Rafael Mestizo Cerón.
Institution and address: Universidad Veracruzana, sede Xalapa. Xalapa, Veracuz, México.
e-mail: rmestizo@yahoo.com

Abstract: Plastic gears have positioned themselves as serious alternatives to traditional metal gears in a wide variety of applications. The use of plastic gears has expanded from low power, precision motion transmission into more demanding power transmission applications. As designers push the limits of acceptable plastic gear applications, more is learned about the behavior of plastics in gearing and how to take advantage of their unique characteristics. Plastic gears provide a number of advantages over metal gears. They have less weight, lower inertia, and run much quieter than their metal counterparts. Plastic gears often require no lubrication or can be compounded with internal lubricants such as silicone. Plastic gears usually have a lower unit cost than metal gears, and can be designed to incorporate other features needed in the assembly. These gears are also resistant to many corrosive environments. It is not very easy to find an appropriate method for calculating tooth stresses and advices for selecting the available materials to use with its respective mechanical properties. Plastic gears can be designed with any tooth geometry. Geometric modifications can go from the traditionally well-known use of shift profile to the total modification of the tooth geometry using not involute profiles, or using asymmetric teeth with involute profile. An analysis of the influence of shift profile and gear asymmetry on the resistance of plastic gears is made at this paper.

***Keywords**: Gears, Plastics, FEM, Failures.*

1. Introduction.

For mechanical engineers the use of plastic gears nowadays is very important due to their low cost and weight, the reduction of noise and other parameters of vital importance in gear applications. The use of plastic gears has expanded from low power, precision motion transmission into more demanding power transmission applications. As designers push the limits of acceptable plastic gear applications,

While metal gears date hundred of years ago, engineers have only a few decades experience using plastic to design gears. At first, manufacturers tried to replace metals with plastic using the same gears designs, but plastics can not be used as a simple droop-in replacement for metals because of enormous differences in material properties, geometry, calculation methods and manufacturing processes. When plastic gears fail, gear makers and gear designers blame for poor quality, but most of the times the real culprits are the engineers who do not understand the fundamentals of plastic gears design.

The most powerful advantages of plastic gears may be the design opportunities they afford. Gear geometries overlooked by designers used to metal are often easy to mold in plastic, and they can reduce drive size, weight, and cost. Geometrical modifications can go from the traditionally well-known use of shift profile to the total modification of tooth geometry using non involute curves or using asymmetric teeth with involute profile.

2. Plastic gears failures.

Plastic gears have different types of failure, standing out among them the following ones "(Basics of Design Engineering, 1996)":

2.1 Adhesive or "Normal" Wear.

This type of wear results from the intermittent welding and tearing of small areas of the opposing wear surfaces. If the welding is at a microscopic level then the result will be a normal uniform wear rate. External lubrication of the gears works to keep the surfaces separated and inhibit wear. PTFE compounded into the thermoplastic acts as a lubricant by forming a thin film of PTFE on both the gear and its mate. This PTFE transfer film has low friction and wear rates. In plastic on plastic gear pairs, at least one of the gears should contain PTFE. Using an external lubricant with PTFE lubricated gears may not give as good a result, since the grease may act as a release agent and prevent the formation of the transfer film. However, since there is a period of break-in on PTFE lubricated gears that will have higher wear rate while the transfer layer forms, a light external lubrication may slow the wear of the gear on start-up if it does not inhibit the formation of the layer. In unlubricated plastic gears failure at the pitch line usually occurs due to non uniform or excessive wear. This kind of wear increases frictional heat (softens material) and increases the pitch line loading on a tooth with a reduced cross section. This usually bends the tooth over at the pitch line, resulting in tooth smearing or complete breakage. This may look like a fatigue failure, but it is really a wear failure. If a gear is well lubricated, then frictional forces are reduced, which will lower the heat build-up and wear. In general, dissimilar materials wear better than similar materials. However, this is not always the case and some sort of wear testing should be performed followed by prototype testing of the gear pair in question if the wear test results look acceptable. If a plastic gear is to be run against a metal gear, the metal gear face should have a finish of 16 μin. for good wear resistance.

2.2 Abrasive wear.

Abrasive wear takes place whenever a hard particle is present between the contact surfaces. This material may be wear debris from one of the gears or dirt from the environment. This type of wear may also be present if one of the gears (usually metal) has a rougher surface than the other. The particles first penetrate the material and then "plow" off pieces of material from the surface. Abrasive wear conditions should be avoided.

2.3 Pitting.

Pitting is defined as a surface fatigue failure that occurs when the endurance limit of the material is exceeded. Gears under load are subject to surface and subsurface stresses. If the loads are high enough and the stress cycles repeated often enough, areas will fatigue and fall from the surface. The area of the pitch line receives the highest stress and is most prone to pitting. Pitting is fatigue related and is generally independent of lubrication.
Pitting is rare in plastics but can occur, especially if the system is well lubricated (low wear).

2.4 Plastic flow.

Plastic flow comes from high contact stresses and the rolling and sliding action of the mesh. It is a surface deformation resulting from the yielding of the surface and subsurface material. Since plastics are insulators and have low melting temperatures (compared to metals) they tend to melt and flow in situations where metal gears would score. In plastic gears the initial plastic flow is in the radial direction. It may not be detrimental as it may relieve itself. However, in more severe cases the flow will be in the axial direction and tooth breakage will soon follow. Plastic flow indicates that the operating conditions are too severe and that failure is not far away. Lubrication (internal and external) can help prevent this condition by lowering the amount of heat generated by friction.

2.5 Fracture.

Fracture is failure by tooth breakage of a whole tooth or at least a good part of it. This can be the result of overloading (stall, impact) or from cycle stressing (fatigue) of the tooth beyond the endurance limit of the material. These types of fractures generally occur at the root fillet and propagate along the base of the tooth.
Fractures in unlubricated systems are usually due to overload. Fractures higher on the tooth are usually wear related.

2.6 Thermal cyclic fatigue.

Thermal cycle fatigue occurs when a temperature rise lowers the material strength and causes pitch line deformation failure, or tooth fold over. Unlubricated and lubricated gears may fail due to thermal cyclic fatigue. Tooth bending stresses always result in some hysteresis heating and since plastics are such good thermal insulators, this results in a material operating temperature rise.

From all these failures, fracture under bending stresses is the main and more common failure of plastic gears. Most of the authors when calculating plastic gears use Lewis' original equation with certain modifications “Bell, (1995)”, "Dvorak, (1988)", "Faires, (1996)", "Fritzinger, (1998)", "Kelley, (1997)". However none of these calculation methods keeps in mind the influence of the asymmetry and of the shift profile in tooth bending strength.

The "AGMA Standard for plastic gears, (1996)" establishes that the correction or shift profile has a remarkable influence on the geometry and therefore in bending strength of plastic gears.

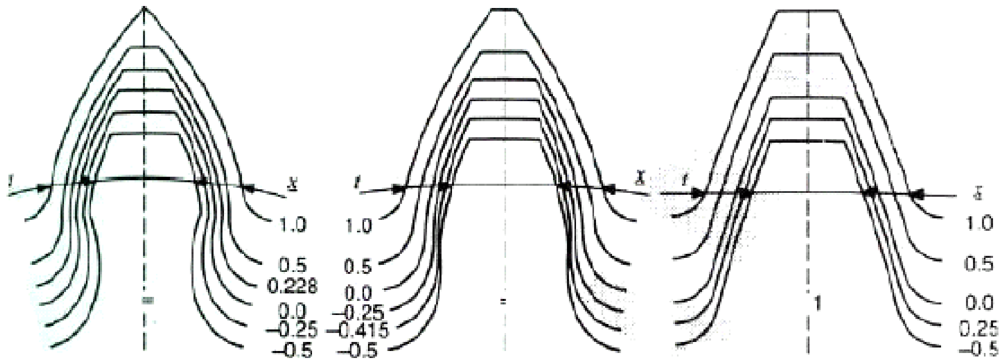

Figure 1: Influence of the correction in the geometric form of the tooth.

However it has not been investigated how diminishes main and resultant stresses when shift profile is used in plastic gears. Some well-known authors as "Zan Smith , (1998)" avoid this aspect. Recently "Alexander Kapelevich, (1998)", published for the first time the variant of using asymmetric gears, beginning then a new era for gear transmissions

3. Influence of tooth geometry on bending strength.

To take into account the asymmetry, the concept of coefficient of asymmetry was introduced. This is not more than the relationship among the coast side angle of the profile, divided by the driving side angle, that is to say:

$$C = \frac{\alpha_{coast}}{\alpha_{driving}}$$

In order to evaluate the influence of the correction, the tooth asymmetry and the combination of both in bending strength of plastic spur gears it was carried out an experiment using the finite elements method. Different values of module, teeth number, face width and driven power were chosen. Then it was analyzed their influence on bending stresses at tooth root for different correction values and asymmetry of the profile. The driving side angle was varied from 17° to 27° and the coast angle in that same range. For each combination of driving angle with coast angle the behavior of the correction was evaluated, introducing shift profile coefficients that varied form X=0 to X = 0,8. Typical values of power, module number of teeth and operating speed for plastic spur gears were used. The variation of bending stresses en z axis for symmetrical gears without shift profile is showed in Figure 2. In figure 3 the same tooth is shown, but now with a coefficient of asymmetry of 1,35.

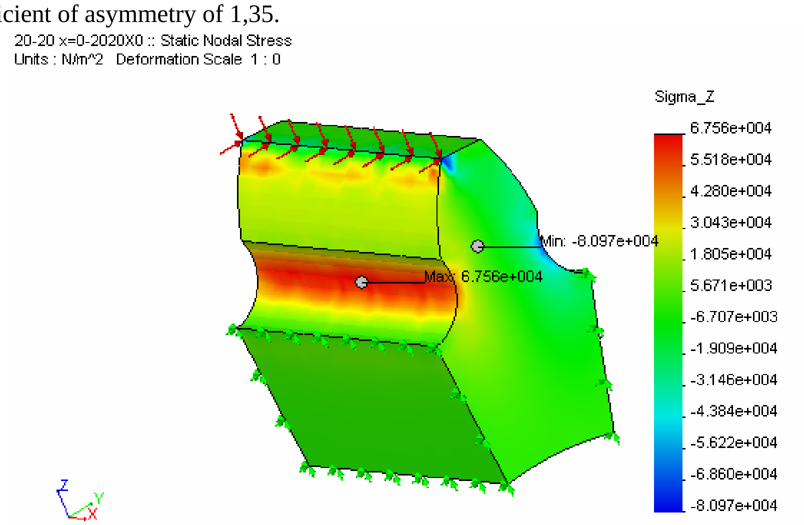

Figure 2. Bending stresses in Z axis for a symmetrical tooth of 20° pressure angle without shift profile.

.

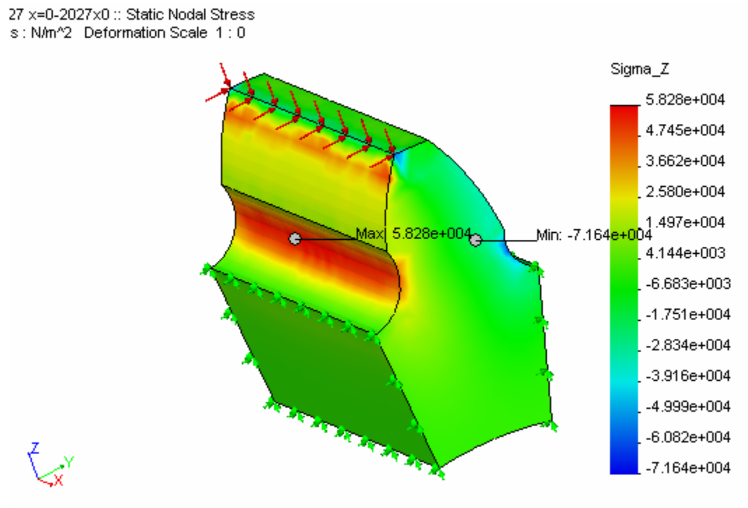

Figure 3. Bending Stresses in z axis for an asymmetrical tooth with driving side angle of 20° and coast side angle of 27°.

The bending stresses variation in z axis according to the coefficient of asymmetry and the correction for a driving angle side of 20º is shown in figure 4

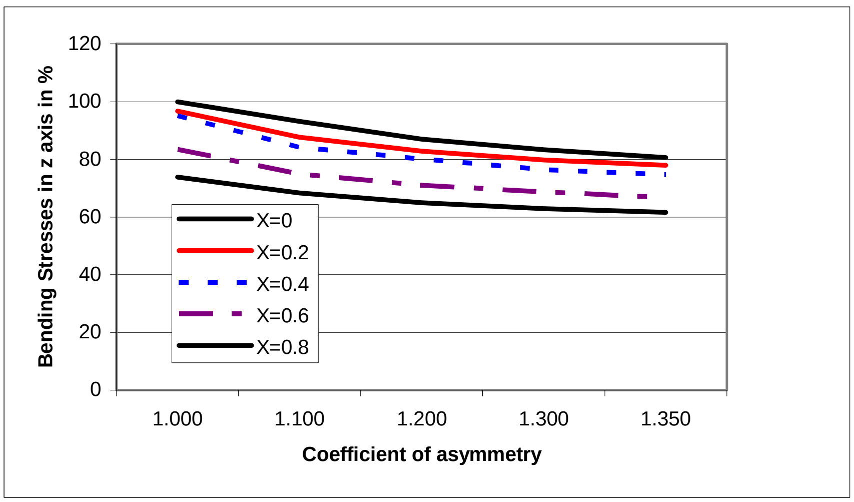

Figure 4 Variation of bending stresses in z axis in function of the coefficient of asymmetry and the correction for a driving side angle of 20°.

4. Conclusions:

Tooth fracture is one of the most frequent failures of plastic gears and geometrical modifications can contribute to avoid or diminish the risk of this failure. However the different calculation methods that exist to determine the dimensions of plastic gears according to power requirements do not take into account the possibilities of geometric modifications of these gears. In the plastic gears geometry plays a fundamental role, since modifications can be made that cannot always be made in metallic gears.

Increasing the coefficient of asymmetry and using shift profile it is possible to increase bending strength of plastic spur gears until to 30%.

5. References:

AGMA 1006 - AXX. Tool Proportions for plastic gears. 1996

Basics of Design Engineering. Machine Design. August 22, 1996 pag. 110. Penton Publishing
Bell Van Laanen Julie. Designing with plastics. Mechanical engineering December 1995.
Dvorak Paul. Bite for live Plastic Gears. Machine Design. January 1988. Penton Publishing ISSN 0024-9119 USA.
Faires Virgil M. Design of Elements of Machines. Editorial Limusa. Mexico 1996
Fritzinger Dan. Basic Training for designing plastic gears. Revista Machine Design. Febrero 1998. Penton
Fritzinger Dan. What to put on part prints of plastic gears. Machine Design. November 1998. Penton Publishing
ISSN 0024-9119 USA.
ISSN 0024-9119 USA.
Kapelevich A. Geometry and design of involute spur gears with asymmetric teeth. Pergamon Press 1998.
Kelley John W. Polymers get in gear. Machine Design 1997 . Penton Publishing ISSN 0024-9119 USA.
Publishing ISSN 0024-9119 USA.
Smith Zan. Gearing up plastics. Mechanical engineering September 1998.

6. Responsibility notice

The authors are the only responsible for the printed material included in this paper.