Basic Loaded Tooth Contact Analysis Theory

INSTRUCTOR:
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COURSE INFORMATION

Course Description
Evaluation of loaded tooth contact and development of tooth modifications using commercially available software to improve and apply a realistic load distribution factor Km in gear rating calculations and reduce transmission error. Two real life gearing examples will be reviewed in the course, one will have a cantilever mounted pinion, the other a shaft pinion straddled non-symmetrically by bearings. Both examples demonstrate component deflections under load which significantly reduce tooth mesh contact which is then corrected with developed helix and profile modifications. Other gear performance optimization tools will also be presented, Material and Heat Treatment Selection, Profile Shift, Isotropic Finishing, Shot Peening, Accuracy. These design tools along with LTCA are commonly applied by gear designers to optimize design reliability and calculated rating safety factors.

It is recommended that you spend a minimum of 1 hour reading and reviewing the material each day.

Who Should Attend
Gear design engineers who are interested in developing state of the art competitive gear designs which provide optimized power density. Gear mesh Loaded Tooth Contact must be evaluated and improved using helix and profile modifications to achieve the assumed load distribution factor which has been applied in gear life and rating calculations. Loaded tooth, shaft and bearing deflections cause tooth mesh contact to shift, reduce in size and concentrate causing the potential for premature gear tooth fatigue failure. There are several other tools in the Gear Designers Toolbox that can be applied to improve tooth contact and bending safety factors. This course would be of interest to experienced gear manufacturing engineers, inspectors, quality assurance and operators to better understand the complex geometry, helix and profile modifications called out on high performance, optimized gear drawings.

Learning Objectives

- Identify the need for Loaded Tooth Contact Analysis and describe the theory behind the contact analysis process
- Model the loaded gear mesh shafts, bearings and gear geometry in commercially available dedicated gearing "FEA" software to calculate magnitude and direction of tooth deflections and deformations.
- Develop and apply tooth profile and helix modifications that compensate for tooth, shaft and bearing deflections, reducing transmission error and optimizing power density
- Describe the tools and processes of contact analysis
- Review cantilever pinion example of contact analysis and corrective action
- Review non-symmetrical bearing mounted shaft pinion example of contact analysis and corrective action
- Present contact analysis Do's and Don'ts
- Review other gear performance optimization tools

Required Textbooks (Provided by AGMA)
Basic Loaded Tooth Contact Analysis Theory manual by Terry Klaves.

COURSE OUTLINE

- Need for and History of Gear Mesh Contact Analysis on high power density gear drives
  - Mesh Contact Analysis was born to understand and correct gearing failures in early wind turbines
  - Traditional methods of identifying and correcting loaded mesh contact required prototype parts, load testing, corrective actions at excessive cost and time.
- Contact Analysis Theory
  - Calculate tooth deflections, form deviations and potential for mesh interference
  - Review potential tooth failures, macro-pitting, micro-pitting, bending fatigue from reduced/shifted/concentrated tooth contact
  - Apply commercial dedicated FEA software solutions to small "slices" of a gear mesh
  - Evaluate each slice as a spring with known stiffness
  - Evaluate resulting projected tooth contact and transmission error, develop flank modifications to improve loaded mesh contact and compensate for deflections/deformations. Improve Khb to validate rating calculations and achieve design fatigue life.
  - Factors affecting loaded mesh contact for a given load point
    - Mesh load and externally applied loads
    - Tooth deflection as cantilever beam
    - Shaft bending/bearing locations relative to face width
    - Torsional windup of helix
    - Bearing deformation
    - Housing deformation if tapered bearings are used
- Corrective Action
  - Develop manufacturable tooth profile and lead modifications, (micro-geometry) to optimize mesh contact, load distribution and predicted fatigue life
    - Helix
    - Profile
    - Twist Error
  - Apply modifications
    - Validate ratings with actual Khb for loaded tooth contact
    - Achieve target design fatigue life
    - Optimize power density
    - Eliminate premature gearing fatigue failures if applied as problem solving tool
- Contact Analysis process
  - Define the application, drive envelope and loading
  - Commercially available Advanced Mesh Analysis/Contact Analysis software runs FEA on gear mesh. Recommendation to procure software or identify capable gear consultant who has and knows how to apply contact analysis software
  - KISSsoft
  - MDesign-LVR

- Pro-E FEA, (the hard way)
- Start with model of gear-shaft-bearing system, individual components or model complete system, (KISSDESIGN)
- Input or output torque, (speed and horsepower)
- Gear mesh geometry, configuration, multiple meshes and their interaction
- Shaft diameter, length, bearing locations, input torque, output torque and any externally applied loads
- Bearing size, location and stiffness constants if available

- Input data into software with no modifications, run contact analysis
  - Evaluate calculated transmission error, graphical representation of flank axial contact position and percent of face width in contact. Evaluate predicted contact and root stresses based on color coded stress distribution graphic. Evaluate calculated load distribution factor and its impact on gear rating/fatigue life
  - Apply software recommended tooth profile modifications and iterate with various helix modifications to optimize mesh contact and load distribution factor
    - Profile modifications – Form of linear, circular or custom, (parabolic), tooth tip modifications, start of modification and amount at tip. Crowned or “barrel” profiles are non-involute forms and do not provide optimum improvements in authors opinion
    - Helix modifications – Form of crown, taper, helix angle, end relief, linear, circular or custom modifications start locations and amounts
  - Rerun contact analysis and iterate with various modifications to optimize mesh contact, transmission error and load distribution.
    - Consider selected accuracy class, (ISO 1328 preferred), for gearing and run contact analysis with gearing and modifications manufactured at maximum tolerance values. Define precise, desired modifications in terms of ISO 1328
    - Consider capability of gear manufacturer when designing modifications, complex modification specifications can cause more harm than good and drive costs up if beyond gear manufactures capability to produce, inspect and verify
- Two examples of industrial drive contact analysis and optimization for applications with cantilever mounted pinion and non-symmetrical bearing location pinion will be reviewed.
  - Cantilever pinion example with multiple load conditions
    - Loading
    - Single mesh drive model
    - Pinion model
    - Gear model
    - Contact analysis with no modifications
    - Cantilever pinion shaft bending
    - Develop optimum helix modification
    - Develop optimum profile modification
    - Contact analysis with modifications at operating load
    - Contact analysis with modifications at alternate loads
  - Non-symmetrical straddle bearing pinion with constant load
    - Loading
    - Single mesh drive model
    - Pinion model

    - Gear model
    - Contact analysis with no modifications
    - Cantilever pinion shaft bending
    - Gear shaft bending
    - Develop optimum helix modification with table of X and Y points which satisfy ISO 1328-1 inspection requirements
    - Develop optimum profile modification with table of X and Y points which satisfy ISO 1328-1 inspection requirements
    - Contact analysis with modifications at operating load
    - Note: Examples are predeveloped, Trainer will not work through "live" KISSsoft calculations
- Contact analysis Do's and Don'ts
- Other gear performance optimization tools
    - Material and heat treat selection
    - Profile Shift
    - Isotropic Finishing
    - Shot Peening
    - Gear Accuracy
- Questions

STUDENT FEEDBACK AND GRADING PROCEDURES

Assignments
Assignments and learning activities are given and directed at the discretion of the instructor.

COURSE MANAGEMENT

Weather Delays and Cancelations
We will communicate any cancellations, delays or other concerns for safety prior to class via email, voicemail, and/or text message. Please be sure that we have all pertinent contact information as you travel to your class location.

Attendance for Domestic and International Students
Please be mindful that these are short, accelerated courses. Attendance is extremely important. If you are going to be absent from any class day, please contact the course coordinator.

Plagiarism, Cheating and other types of Misconduct
Plagiarism[1], cheating and other types of misconduct are unacceptable.

Students with Disabilities
Students requiring assistance and accommodation should complete the Special Accommodation Request form and submit it to Stephanie Smialek, Education Manager at smialek@motionpower.org. She can be reached at 773-302-8026.

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[1] Plagiarism is defined as "the use or close imitation of the language and thoughts of another author and the representation of them as one's own original work."

Grievance Procedures
Students who have concerns about the class are encouraged to contact Stephanie Smialek, Education Manager, at smialek@motionpower.org or 773-302-8026.

Outline Changes
The instructor reserves the right to modify the outline during the course of the class.

LEARNING AND OTHER RESOURCES

Links for writing resources:
- grammar.ccc.commnet.edu/grammar
- www.merriam-webster.com

Links for Math resources:
- www.sosmath.com
- Khan Academy on www.youtube.com

Links for time management, study skills and note taking resources:
- www.mindtools.com
- www.testakingtips.com

Links for career resources:
- https://www.agma.org/newsroom/jobs/

Industry News:
- https://www.agma.org/newsroom/industry-news/