On-Site Training Course on Bolted Joints

for Engineers and Designers

A training course delivered at a company's facility by Matrix Engineering, an approved provider of Bolt Science© Training

Two Day Training Course Content

Following is an outline of the material covered in the training course. Each person on the course will be provided with a handbook which contains background information to the material presented in the course, including example calculations, tables of thread stress areas, thread shear areas and fastener material strength details. Following presentation of the background theory, problems will be presented relating to the topic. Full answers are provided in the course documentation.
The course includes a number of case studies will be reviewed. These case studies are drawn from the automotive, naval, petro-chemical, power generation and railway industries. The course also includes hands-on demonstrations of torque tightening, torque and angle tightening and excessive bearing stress.

Customized Training: *The course content can be modified to suit specific requirements of a company or organization. Customization may include unique fastener sizes, materials or conditions. Rather than using the standard cases studies, the training can incorporate specific problems provided by the client.*

Introduction to Threaded Fasteners

- ❑ Know the meaning of thread terminology.
- ❑ Background to modern threads - the roles of Whitworth and Sellers and the development of the metric thread.
- ❑ Learn the difference between a fine rather and coarse thread and advantages/disadvantages of each.
- ❑ Be aware of the principal bolt and nut strength property classes and how they should be specified.
- ❑ The basic profile of Unified and metric thread forms.
- ❑ Thread tolerance positions and grades and the different tolerance classes that are available.

Strength of bolts

- ❑ The principles of bolt elongation, bolt stress and load and gasket stress.
- ❑ Yield, tensile strength and proof load properties.
- ❑ Details of common bolting specifications.
- ❑ Bolt and nut head markings and identification of correct components.
- ❑ Nut/bolt combinations, nut strength versus bolt strength.
- ❑ Upper and lower temperature limitations of common bolting materials.
- ❑ Relationships between bolt size, area, stress and bolt elongation and load.

Stress Area of a Thread

- ❑ Factors determining the strength of a thread.
- ❑ Tests completed to establish the strength of threads, the original work of Eli Slaughter.
- ❑ How the stress area was established.
- ❑ Determination of the stress area of a thread. elongation and load.

Methods of Tightening Threaded Fasteners

- ❑ Overview of the methods used to tighten bolts.
- ❑ Load-angle of turn graph for a bolt tightened to failure.
- ❑ Torque controlled tightening method.
- ❑ Torque-angle tightening below the yield point.
- ❑ Projected angle tightening method below the yield point.
- ❑ Yield point tightening using incremental angle method.
- ❑ Yield point tightening method using slope measurement.
- ❑ Torque-angle tightening method into the plastic region.
- ❑ Yield control tightening plus an angle increment.
- ❑ Limited re-use of bolts sustaining plastic deformation.
- ❑ Bolt tensioning using hydraulic tensioning method.
- ❑ Tightening by elongation measurement.
- ❑ Heat tightening of large bolts
- ❑ Tension indicating methods using load indicating bolts and washers.
- ❑ Application of ultrasonic technology in bolt tightening.

Torque Control

- ❑ What is meant by a tightening torque. Units used to measure torque.
- ❑ What are the consequences of not applying sufficient torque to a bolt.
- ❑ How torque is absorbed by a nut/bolt assembly.
- ❑ The torque-tension graph.
- ❑ The relationship between the tightening torque and the resulting bolt preload (tension).
- ❑ The factors which affect the torque-tension relationship.
- ❑ The nut factor method of determining the correct tightening torque.
- ❑ Using the full torque-tension equation to determine the appropriate tightening torque.
- ❑ Example calculation of how to determine the correct tightening torque.
- ❑ Scatter in the bolt preload resulting from friction variations and torque technique.
- ❑ Tests to determine the coefficient of friction of threaded fasteners.

Tightening Procedures

Problems associated with the tightening of multi-bolt joint.

- ❑ Elastic interaction and bolt cross-talk.
- ❑ Single pass tightening sequence.
- ❑ Two pass and multi-pass tightening sequences.
- ❑ Tightening sequences for non-circular bolted joints.
- ❑ Tests investigating the effects of elastic interaction.
- ❑ Use of multiple tightening tools.
- ❑ Hydraulic tensioning.
- ❑ Ways to check the tightening sequence.
- ❑ The solder plug method.
- ❑ The use of pressure sensitive film.

Torque Tightening/Torque-Angle Demonstration

- ❑ Demonstration/Comparison of two bolt tightening techniques using a Skidmore Devise.
- ❑ Preload scatter of M10 using torque tightening without lubrication.
- ❑ Preload scatter of M10 using torque-angle tightening with lubrication.

Quality Assurance & Control of Fastener Assembly

- ❑ Principles of torque auditing.
- ❑ Dynamic and static torque measurements.
- ❑ Methods of checking installed torque values.
- ❑ The "Crack-On" method of torque checking.
- ❑ The "Marked Fastener" method.
- ❑ The "Crack-Off" method of torque checking.
- ❑ Torque "Go-No-Go" Assessment.
- ❑ Problems with Torque Auditing.

Why Tighten a Bolt?

- ❑ Why is tightening a bolt important?
- ❑ How a preload joint sustains an axial load.
- ❑ The "Bolted Joint Enigma".

Two Day Training Course Content

Joint Diagrams and Load Factor

- History and Explanation of Joint Diagrams.
- Comparison of Soft and Hard Joints
- Explanation of Load Factor
- Calculation of Load Factor – Sample Problem
- Load Introduction Factor

Overview of Fastener Failure Modes

- Overview of the ways threaded fasteners can fail.
- Manufacturing Related Quality Defects.
- Design Related Quality Defects.
- Failure by insufficient preload - examples including joint slip, joint separation and gasket sealing failures.
- Fatigue failure of bolts.
- Thread Stripping Failures - internal and external threads.
- Bolt overload from applied forces.
- Bearing stress under the bolt head or nut face.

Self Loosening of Threaded Fasteners

- Overview of the research completed over the last 50 years into establishing the cause of the self-loosening of threaded fasteners.
- Appreciate the forces that are acting on the threads that tend to self loosen a fastener. Why fine threads can resist loosening better than coarse threads. The inclined plane analogy.
- Learn about the work completed by Goodier and Sweeney into loosening due to variable axial loading.
- The work completed by ESNA and the theory of shock induced loosening and resonance within fasteners.
- The MIL-STD 1312-7 vibration test for fasteners.
- Junker's theory on self-loosening of fasteners and why fasteners self-loosen.
- The Junkers/transverse vibration test for fasteners.
- The influence that vibration amplitude has on the fastener self-loosening rate.
- Preload decay curves and the effectiveness of various fastener types in resisting vibrational loosening.
- Conclusions from the research and how loosening can be prevented.

Thread Stripping

- Identify the cause of thread stripping.
- Be able to establish the shear area of an internal or external thread.
- How the tapping drill size affects the strength of the bolt thread.
- How the radial engagement of threads affects thread strength and the failure load.
- Use the information provided on the course to calculate the internal and external thread areas and the force needed to cause the threads to strip.
- Be able to establish the length of thread engagement needed to prevent thread stripping.

Galling of Threaded Fasteners

- Background and explanation of galling.
- Types of fastener material and finishes susceptible to galling.
- Examples of thread galling.
- Approaches that are used to prevent/minimize galling.

Hydrogen Embrittlement of Fasteners

- Background to hydrogen embrittlement.
- Fracture characteristics associated with this type of failure.
- The cause and mechanism of hydrogen embrittlement.
- Checking for hydrogen embrittlement - paraffin test.
- Lower temperature heat treatment after plating.
- Stress corrosion cracking and the influences of the operating environment, the bolt stress and the bolt material.

Excessive Bearing Stress

- Difference between excessive bearing stress and embedment.
- The stress-cone concept.
- Calculation of bearing stress and comparison to critical surface pressure.
- Demonstration of the effects of washer on bearing stress in aluminium sample.

Fatigue of Threaded Fasteners

- Understand the causes of fatigue to be able to recognise this type of failure.
- Learn about the S-N diagram and the endurance strength of a threaded fastener.
- Understand the difference between the load acting on a joint and that sustained by a bolt.
- The different approaches that can be used to establish the endurance strength of a pre-tensioned threaded fastener.
- Learn about the effect that joint face angularity can have on the fatigue performance of a fastener.
- Learn how the fatigue performance can be improved.
- The effect that bolt diameter has on fatigue performance.

Fasteners at Low or Elevated Temperatures

- Overview of the effect of decreasing or increasing the temperature that the joint was assembled at.
- Temperature ranges of common bolting materials.
- The effect of differential thermal expansion
- Transitory temperature effects.
- Effect of temperature on the yield strength of common bolting materials.
- Effect of temperature on the modulus of elasticity.
- Stress relaxation and the effect on the bolt preload.
- Example calculation accounting for differential thermal expansion and stress relaxation.

Fastener Finishes and Corrosion

- Background and types of corrosion.
- The galvanic series and barrier and sacrificial protection.
- The mechanism of galvanic coupling.
- Provision of sacrificial protection of steel fasteners.
- Effect of the coating thickness on thread dimensions.
- Maximum coating thickness for class 6g threads.
- Salt spray testing and the performance of various finishes.

Bolts in Direct Shear

- Friction grip and direct shear bolted joint designs.
- Issues with bolts loaded in direct shear.
- Shear capacity in direct shear.
- Example calculation - direct shear loading.
- Joints consisting of multiple bolts.
- Joints sustaining direct shear and axial loading.
- Example problems for the student to resolve.

Shear Loads applied to Bolted Joints

- What is meant by an eccentric shear load..
- Understand the slip process that can occur with shear loaded joints.
- Learn what is meant by the instantaneous centre of rotation for the joint.
- Be able to calculate the reactions of individual bolts when shear forces are applied to the joint.
- Perform example calculations so that you have confidence to use them in practical applications.

Combined Tension and Shear Loading

- What is meant by an eccentric shear load.
- Understand the slip process that can occur with shear loaded joints.
- Learn what is meant by the instantaneous center of rotation for the joint.
- Be able to calculate the reactions of individual bolts when shear forces are applied to the joint.
- Perform example calculations so that you have confidence to use them in practical applications.
- Learn the methods that can be used to analyze joints subjected to combined tension and shear loads.
- Understand what is meant by prying and its effects.
- Two methods that can be used to determine the neutral axis of the joint when combined tension and shear loads are acting
- Perform example calculations so that you have confidence to use them in practical applications.

Preload Losses Due to Embedment

- Explanation of embedment
- Current understanding of embedment and parameters which affect it.
- Embedment and the Joint Diagram
- Loss of preload due to embedment – springs in series.
- Best guess values from VDI 2230.
- Effect of joint thickness on embedment losses.
- Effects of paint in bolted joints.
- Methods of reducing embedment preload loss.

Overview of FEA Methods to Determine Bolt Reactions

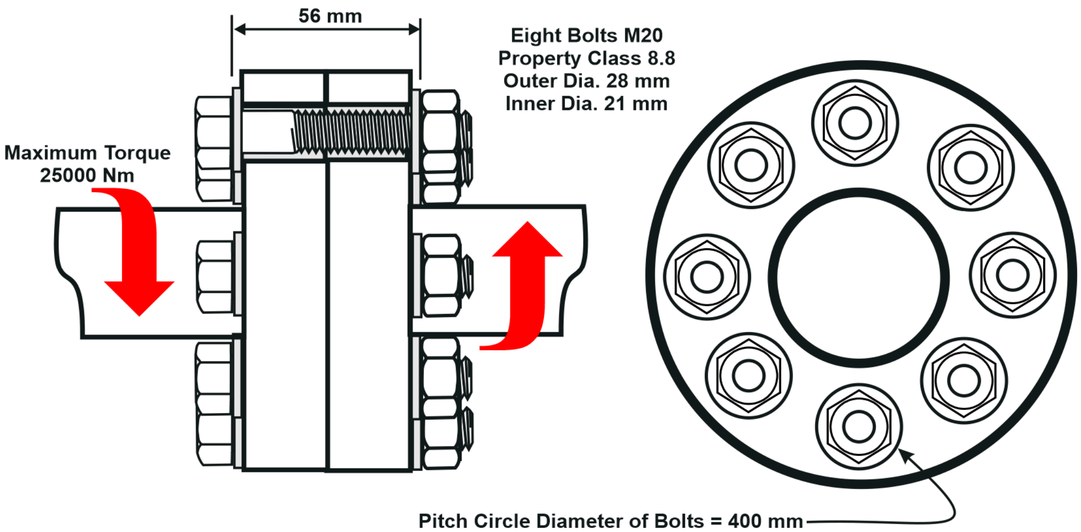
- What is applied axial load?
- Joint diagrams and FEA
- Should I use FEA to determine the axial force requirement at the bolts?
- Description of VDI 2230 Class IV, III and II finite element models.
- Advantages and disadvantages of each.
- Factors often not addressed in FEA models.

VDI 2230 Systematic Calculation of Bolted Joints

- Why are systematic methods important?
- Development of Joint Diagrams.
- VDI 2230 Background and range of validity.
- Key concepts of VDI 2230, failure modes of bolted joints.
- VDI 2230 - The Calculation Steps
- Limitations of VDI 2230
- Software based on VDI 2230

Preload Requirements Charts

- How to prevent the majority of bolting issues.
- Determining the maximum and minimum preloads.
- How to calculate the likely embedding loss.
- Establishing the axial force requirement.
- Establishing the shear force requirement.
- Determining the total force requirement for the joint
- Example calculations
- Ways in which a bolting design problem can be resolved.
- Example problems for the student to resolve.



Is the drive joint shown likely to fail under the given dynamic loading condition?

What is likely to be the problem and how can the issue be rectified?

What tightening torque should be applied to the fasteners?

Typical Questions Addressed in the Training

Can it be anticipated that the joint will fail due to:

- ❑ *Insufficient preload?*
- ❑ *Bolt Fatigue Failure?*
- ❑ *Thread Stripping?*
- ❑ *The bolts/nuts self-loosening?*
- ❑ *Bolt Overload?*
- ❑ *Thread Stripping?*

If there is a problem identified, how can joint be modified so that it will be fit for purpose?

How do you quantify in a calculation methodology the bolt preload scatter associated with the tightening process?

How can the effects of joint relaxation be quantified at the design stage?

Do I really need to use some kind of locking device?

What tightening torque should be applied to a fastener? How can this be established without testing? What tests can be completed? Should the nut or bolt be tightened, or does it not matter?

Why a stronger bolt is not necessarily better?

Is it better for a bolt to fail by tensile fracture during the tightening process or sustain thread stripping?

What are the advantages in using other tightening methods rather than torque control?

What ways can be used to check the 'tightness' of a previously tightened fastener?

Under what specific circumstances does a fastener self-loosen and how can it be prevented?

Why are many locking devices that research indicates are ineffective, still being used?

Training Course Instructor

The training course will be presented by Jon Ness, PE. Jon has over 27 years of engineering and design experience related to the development of mobile equipment components and sub-systems, including dynamically loaded bolted joints. His work has included the design of multiple gear boxes, powertrain systems, engine installations and the development of test and validation plan strategies. He has taught numerous classes related to Failure Modes and Effects Analysis and Bolted Joint Design for design engineers.