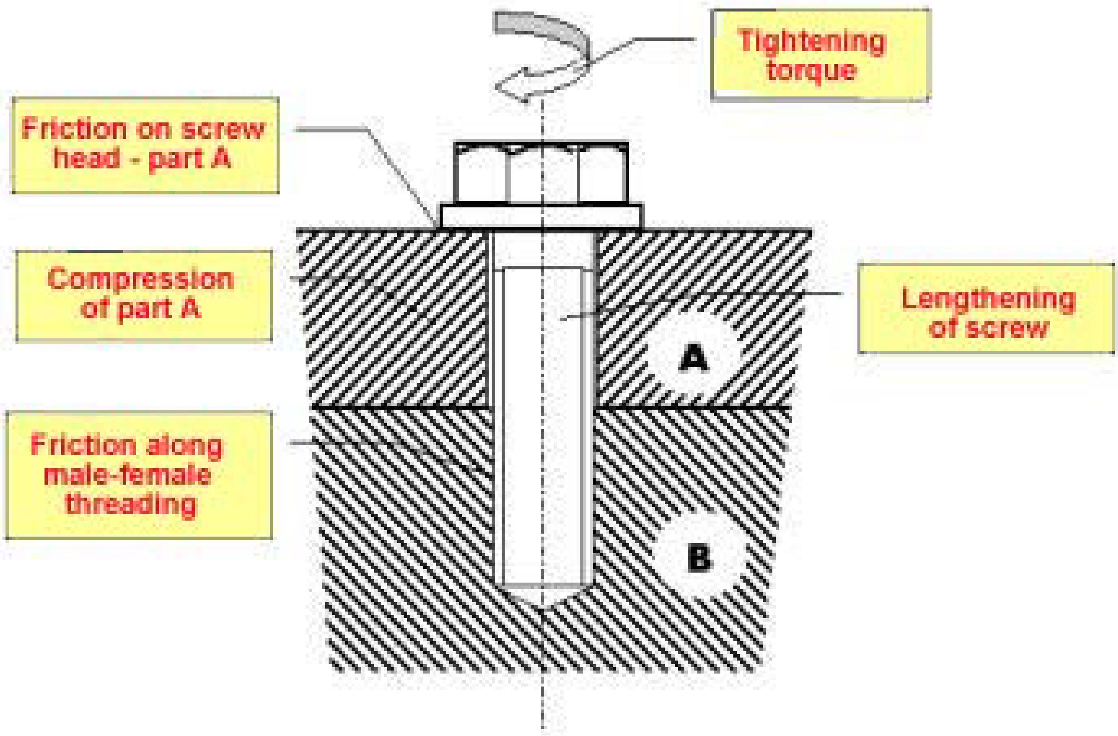
MECHANICAL MAINTENANCE

SCREWS, NUTS & BOLTS



TRAINING MANUAL
COURSE EXP-MN-SM045
Revision 0

MECHANICAL MAINTENANCE

SCREWS, NUTS & BOLTS

CONTENTS

1. OBJECTIVES

This document aims to enable maintenance operators to differentiate between the different types of screws, bolts, nuts and washers which may be found on wellsites.

2. DEFINITION AND CHARACTERISTICS

A bolt consists of a screw and a nut. It is designed to assemble parts.

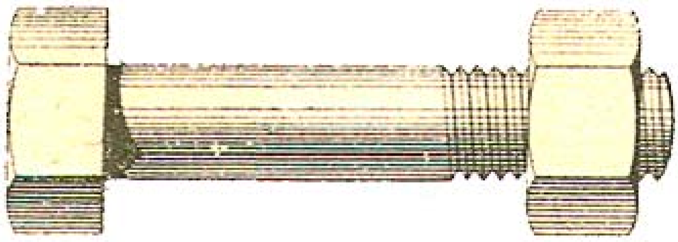


Figure 1: A bolt

2.1. DEFINITION

A bolt is an assembly consisting of a screw and a nut (and possibly a washer).

A bolt is a prestressed assembly. The mechanical traction maintained in the stem causes friction which prevents the rotation of the screw head and of the nut in terms of the fixed component.

A bolt is defined with the following properties:

- Those of its screw
- Those of its nut
- The common properties of the nut and screw

2.1.1. The properties of the screw

- Head shape: hexagonal, square, cylindrical, countersunk, hollow hexagonal.
- Head arrangement, relating to the handling system: slots, indents, etc. (for screwdrivers, allen keys, etc.)
- Length of the stem and the thread (defined in standards).

A screw is a mechanical component, consisting of a threaded stem and a head, designed to attach one or several heads by means of pressure. Screw attachments are complete, rigid and removable connections.

Figure 2: A few screw head shapes

2.1.2. The properties of the nut

- Shape
- Height

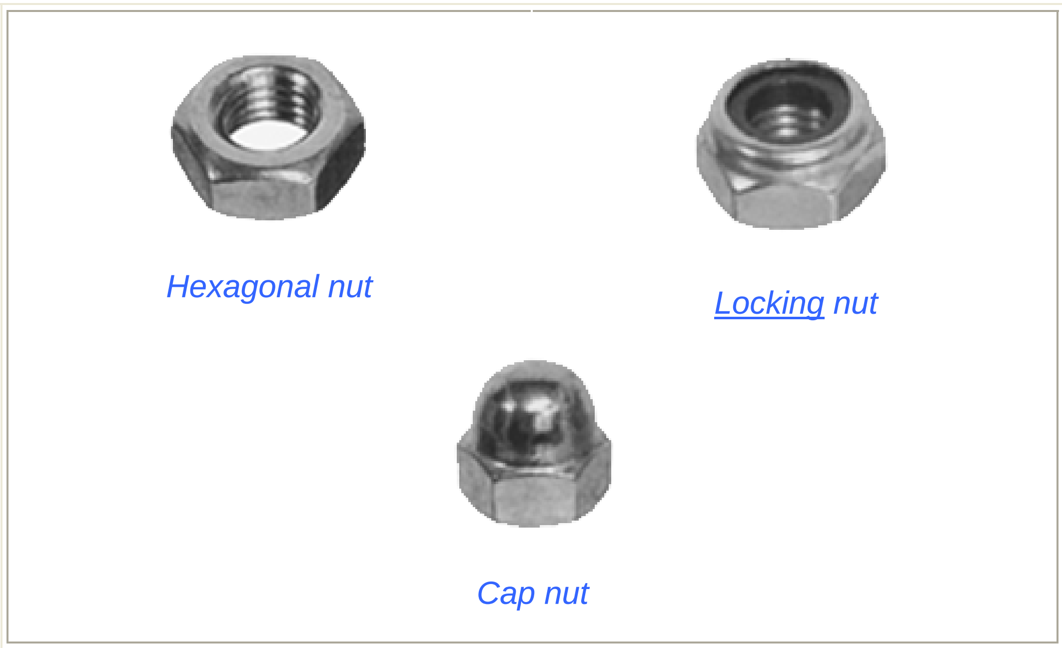


Figure 3: A few nut shapes

2.1.3. The common properties of the nuts and screws

- main thread diameter
- thread form and pitch
- material (steel, stainless steel, Aluminium, etc.)
- coating < for steel bolts only > (hot galvanised or heat treated, electro-galvanised, bichromate plated, raw, etc.)

2.2. FUNCTIONING

A screw is a device capable of transforming a rotational movement into a translational movement directed along the axis of rotation, or vice-versa.

Demonstration

As it turns, the screw moves the nut to the right or to the left depending on the direction of rotation. This system creates a strong force.

A rotational movement is thereby transformed into a translational movement.

The reverse process is also possible, providing the thread pitch is long enough.

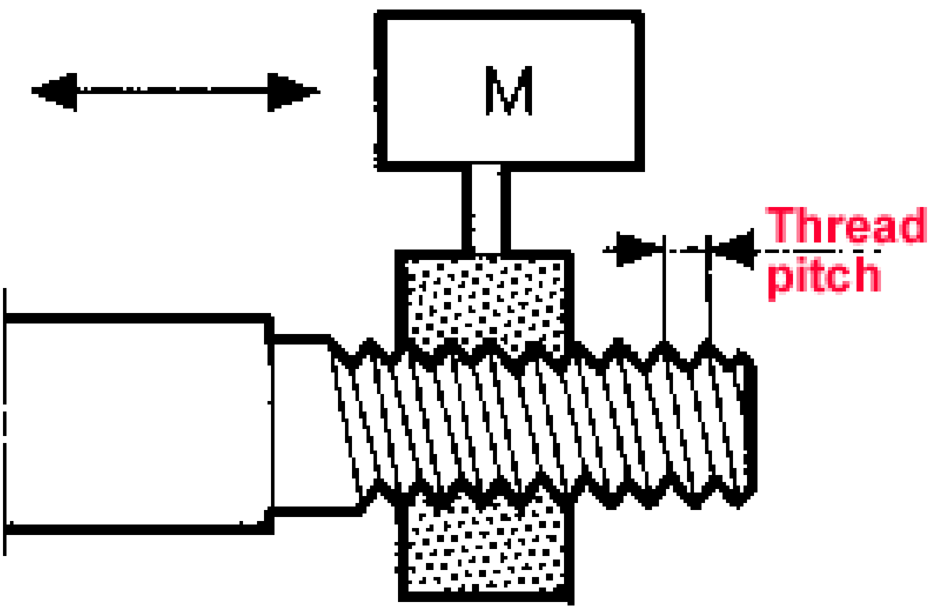


Figure 4: Movement of the nut depending on the direction of rotation

2.3. WASHERS

A washer is a thin disk with a hole, generally in the centre. It is used to absorb the pressure of a screw or nut.

Washers with thicknesses of more than 1mm also exist (e.g.: 2.5mm; 3mm; 5mm). In this case, these are referred to as spacers rather than washers.

Figure 5: A few types of washers

2.4. THREADING

A thread consists of one or more helical grooves on a cylindrical surface. The term thread is used particularly when on the external surface. However, the term thread is often used to refer to the Ø of internal threads for maintenance.

E.g. a nut with a Ø 12 thread, or a hole in the support frame of an engine with a Ø 8 thread, etc.

An internal thread is the complementary half to an external thread. Technically speaking, it is a smooth hole in which has been threaded.

3. GENERAL

Bolting is considered to be standard when it satisfies all criteria in the applicable standard (head shape and dimensions, thread length).

If a washer is used with a screw, the washer must be harder than the screw (to assemble a part and tighten). Washers placed under the heads of screws must not rotate during the tightening of the screw.

Washers may sometimes be softer than screws (e.g. Teflon, nylon, copper). In this case, the aim is to improve a seal.

Screws (and nuts) are used for:

- The assembly of at least two parts. One of the parts may be used as a nut and have an integrated internal thread.
- Pressure-based assembly, the screw is then used as a means of pressure.
- Stopping a part. The screw acts as a stop.
- Guiding rotation or translation.
- Setting a position.

Sizing will be considered from the design phase of the assembly for all uses and more particularly for assembly screws.

It is easy to forget that this everyday mechanical part is a crucial component.

Industrial bolting satisfies strict standards which we will now consider. In addition, industrial bolting includes "engraved" references: these references will also be explained in this course.

3.1. DIFFERENT TYPES OF THREAD

3.1.1. Thread pitch

This corresponds to the relative distance covered in translation by a screw as compared with its nut in one complete rotation. (E.g. a screw with a metric pitch of 5 <pitch in mm> will advance by 5mm during one rotation).

The pitch is the distance between 2 thread crests (or 2 thread roots).

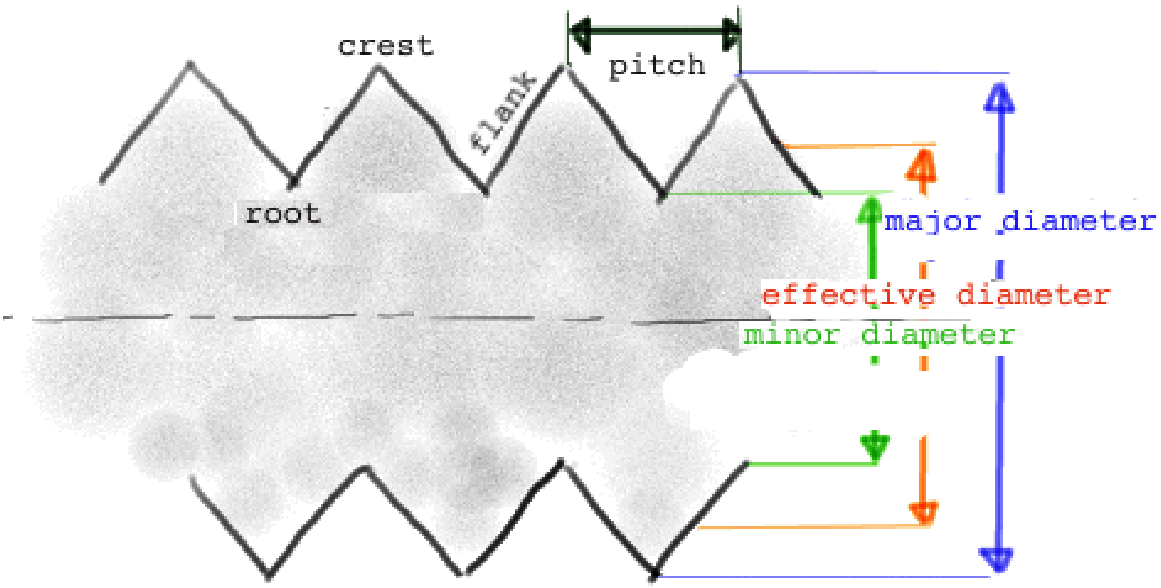


Figure 6: Thread pitch

3.1.2. The thread

A thread is a helical structure used to transform rotation into translation and vice versa.

This structure may be wound around a solid cylinder, such as a screw, or inside a hollow component, such as a nut.

3.1.2.1. S.I. threads

The SI thread was defined by the congress in Zurich in 1898. It has been used for bolting in many countries, including France, Germany and Italy.

The SI thread is triangular, formed by an equilateral triangle whose side is equal to the thread pitch.

The following very simple rule is obtained from this characteristic, and the shape of thread crests and roots:

To create a threaded hole of *x* mm, we need to pre-pierce a tap drill at *x* less the pitch.

E.g.: to create a threaded hole of 10 (pitch = 1.50mm), you need to pierce a tap drill of 8.5mm.

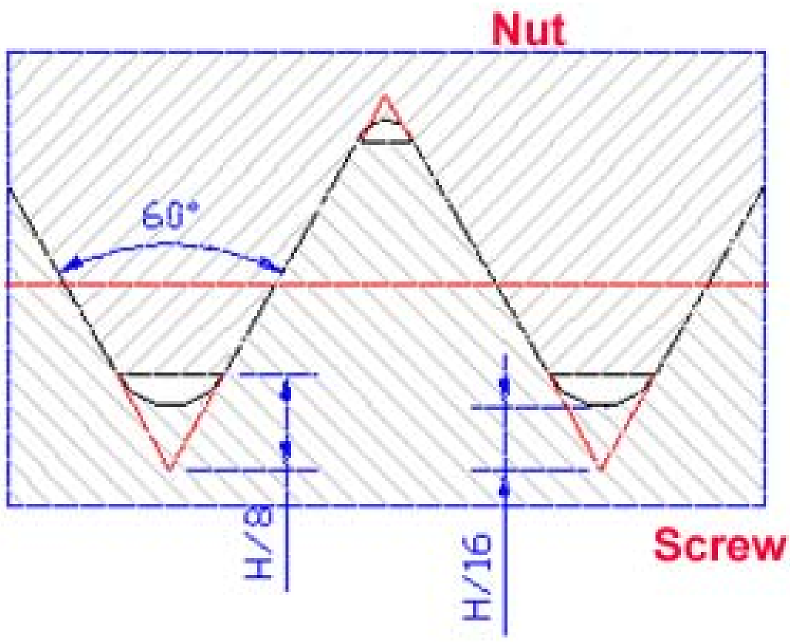


Figure 7: S.I thread

The SI thread was replaced by the ISO thread in 1959

3.1.2.2. Metric I.S.O. thread

- This thread is derived from the former SI system, NFE 03.001, 03.013 and 03.014. Its use has become general and is currently the standard profile.
- Dimensions in mm, diameters 1-68mm.
- Exists for coarse pitches (> normal) and fine, or even extra-fine pitches for certain diameters.
- Designations start with the letter "M" (>> for metric) followed by the diameter and the pitch: E.g.: M10x1.5 (diam. 10; normal pitch =1.5) or M10x1.25 (diam. 10; fine pitch 1.25).

- This is the most frequent type of thread used.
- Designation in millimetres.

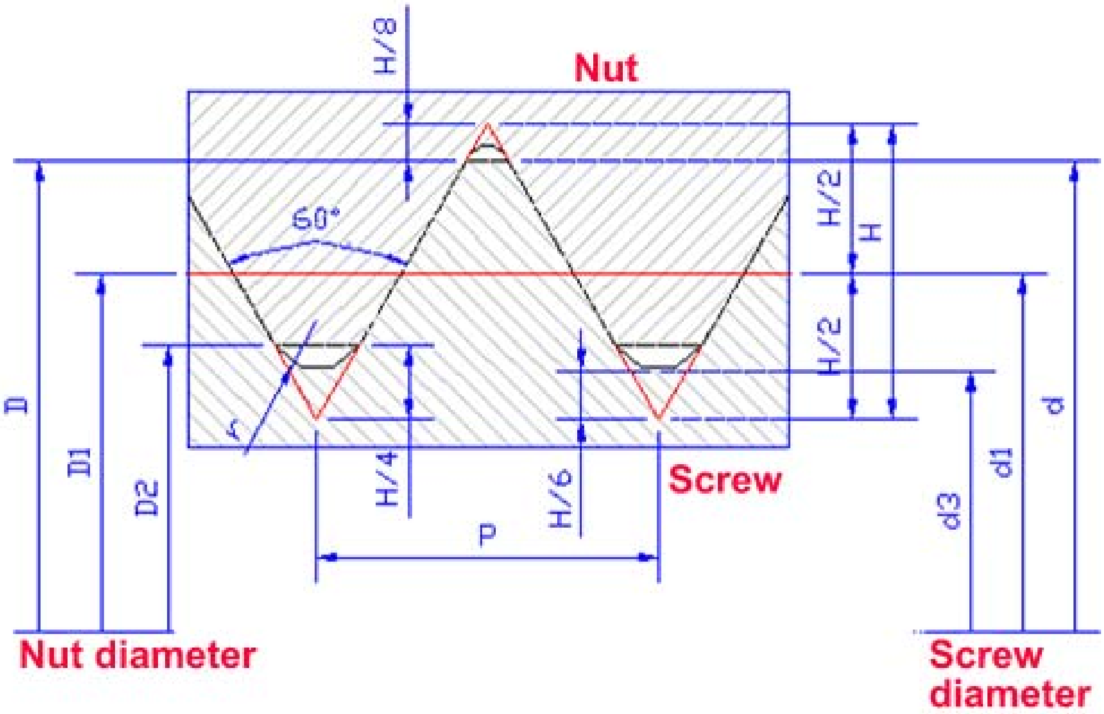


Figure 8: Metric I.S.O. thread

3.1.2.3. SI / ISO interchangeability

This is not a problem. The two standards apply the same thread shape, pitch and diameters, so full interchangeability exists between SI and ISO (for threads with the same diameter and pitch obviously). A few exceptions exist to the above, for small diameters.

In fact, as the diameter of the tap drill is generally larger than the diameter of the SI profile, we are faced with an ISO configuration whether we like it or not, and you can fit an ISO screw in an SI bolt without any problem.

Two series of pitches exist for SI /ISO bolting:

- coarse pitches (>> normal), which are found everywhere. E.g.: diameter 10: pitch 1.50mm.
- fine pitch, used when we need more threads in contact. Several fine pitches exist for certain screw diameters. E.g. pitches of 0.75mm, 1mm and 1.25mm exist for a diameter of 10.

SI/ISO

interchangeability for small diameters

For diameters 1.6, 1.8, 3, 4 & 5, ISO and SI threads are not interchangeable due to the differing pitches. ISO thread tolerance is not as expansive as SI tolerance.

3.1.2.4. UST I.S.O thread

- The ISO Unified Screw Thread profile is often found in the USA, Great Britain and Canada. This profile is identified with UNC, UNF or UNEF coding depending on the value of the pitch: Coarse, fine (F) and extra-fine (EF).
- It is based on a 60° triangle, but with a root radius and thread crest for the screw.
- Dimensions are in inches, with a major diameter ranging between 1/4 and 4 inches. Coarse, fine and extra-fine pitches exist.
- Important: do not mix-up with the metric ISO thread.

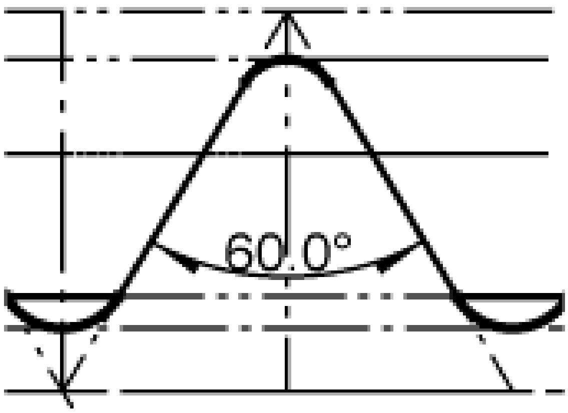


Figure 9: UST I.S.O thread

3.1.2.5. Trapezoidal ISO thread

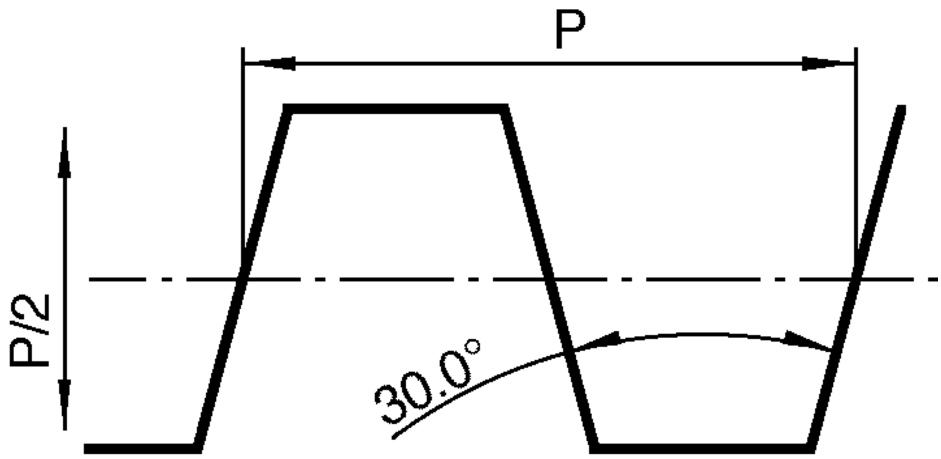


Figure 10: Trapezoidal ISO thread

- NF E 03.002.
- The trapezoidal profile is able to absorb heavy loads.
- It is used for guide functions.

3.1.2.6. Round threads

- NF E 03.003.
- System used in France to connect tank trunks (NF E 29.579).

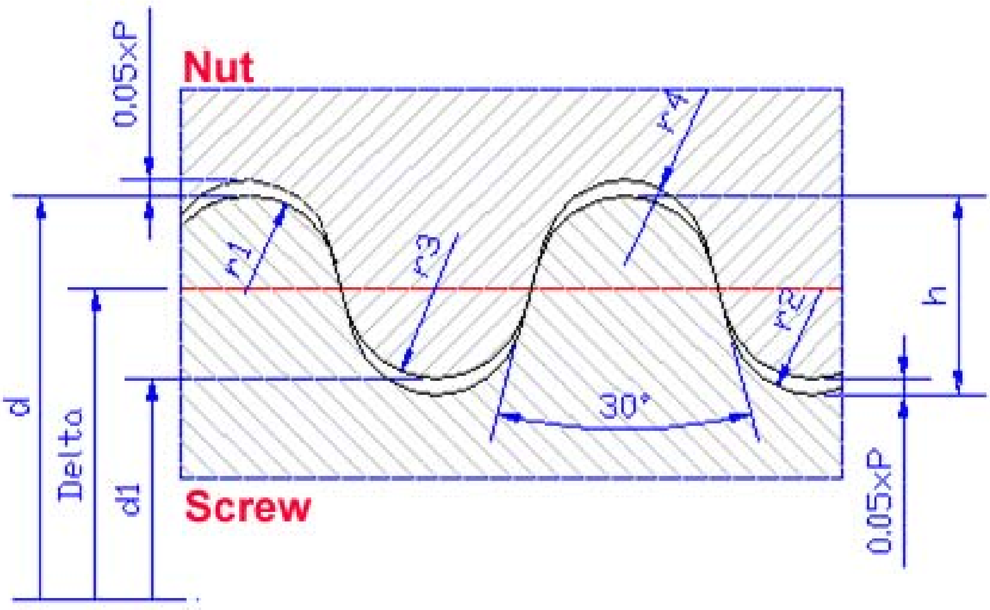


Figure 11: Round threads

3.1.2.7. Whitworth threads – BSW (British Standard Whitworth)

- This thread is British in origin. It is used far less frequently than the ISO profile, but it does still come up, and not just in the UK! This thread is used for safety components (e.g. shackle handles) to prevent the use of any old screw falling to hand.
- This thread is absolutely incompatible with ISO threads.
- BS-84 1956 table 2.

- This thread is frequently used in the oil industry.

BSW >> normal pitch

BSF >> fine pitch

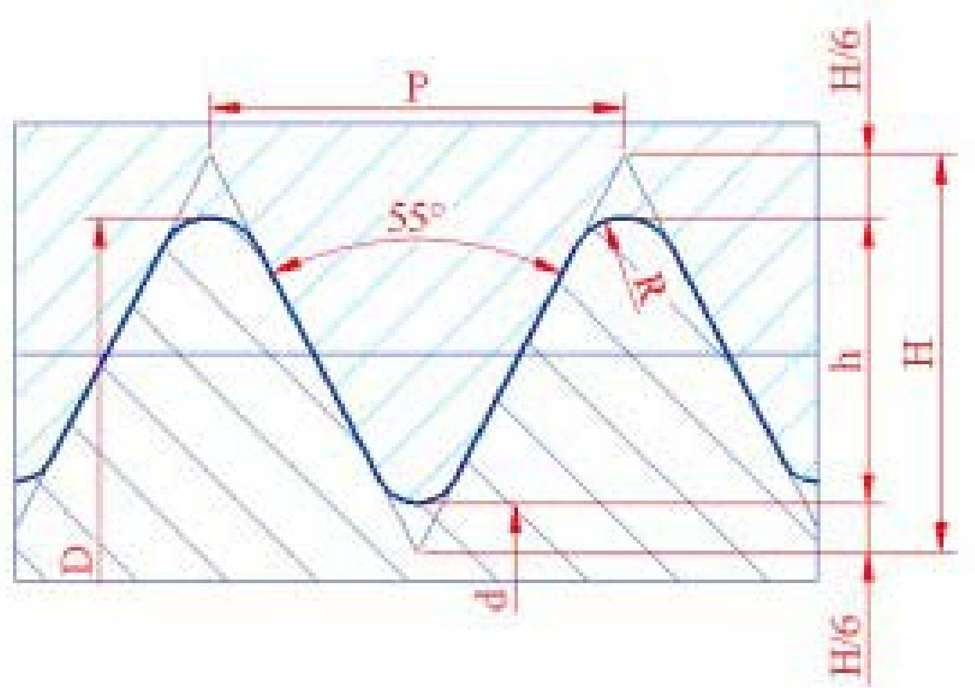


Figure 12: Whitworth BSF thread

3.1.2.8. API thread

(American Petroleum Institute). API Std 5 L.

These threads are used in the oil industry. Their characteristics are designated in inches.

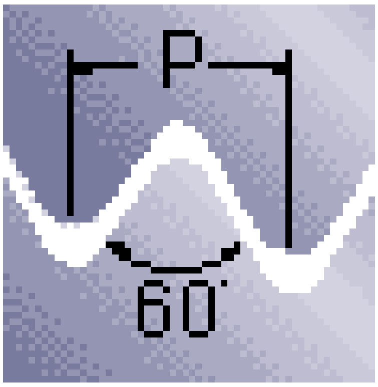


Figure 13: API thread

3.1.2.9. BRIGGS Standard (NPT) thread

- American standard A.S.A B2.1.1945.
- Officially known as NPT (National Pipe Thread). American standard.
- Their characteristics are designated in inches.

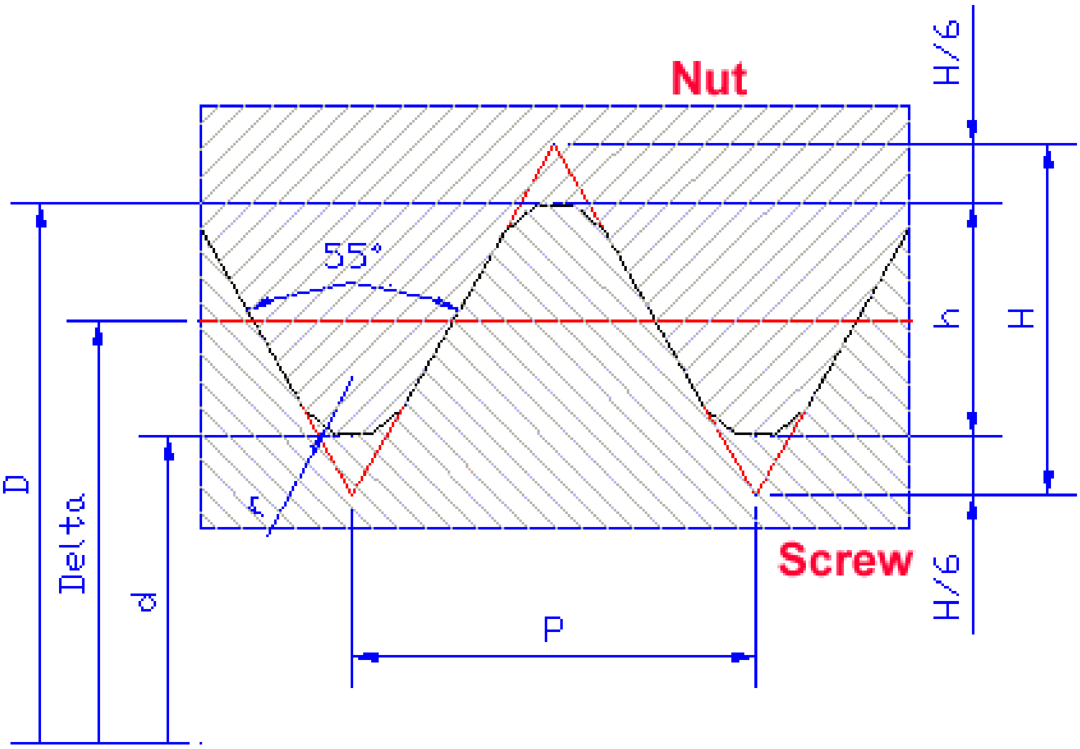


Figure 14: BRIGGS STANDARD (NPT) thread

3.2. DIFFERENT TYPES OF ASSEMBLIES

A bolt installed in satisfactory conditions will act as a spring.

Mechanical resistance of an assembly

If a connection is well designed, only a small percentage of external forces will transit via the screw(s) >> consequence of the prestressing of the assembly. Pre-stressing is created by the torque applied by the assembly tool.

Several types of assembly exist:

- Permanent

- Removable
- Direct
- Indirect

3.2.1. Permanent

The connection cannot be removed without destroying at least part of the assembled components.

- Welding
- Riveting

3.2.2. Removable

The connection is designed to be removed and re-installed without damageing the parts.

- Screwed (bolt/screw)

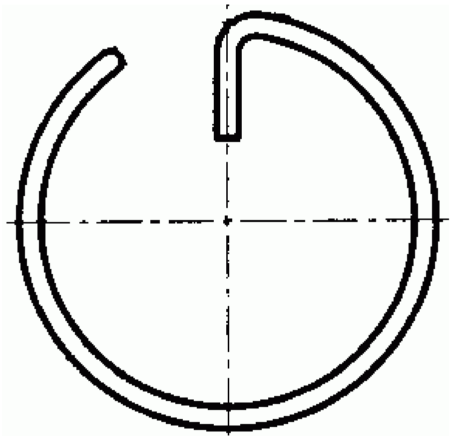
3.2.3. Direct

- Stapling >> attachment of thin materials
- Bracing >> assembly using tight adjustments
- Sealing >> Adhesion
- Welding >> Continuity with the material assembled
- Punching >> stamping technique
- Bolting >> screw/nut

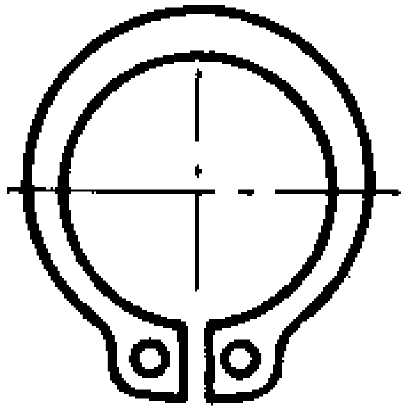
3.2.4. Indirect

- Elastic ring >> generally fitted in grooves. Enables axial stops (spring retaining rings)
- Key >> connects 2 rotating parts

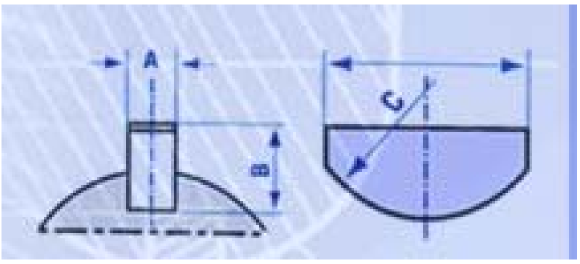
- Pin >> required with shearing



Elastic retaining ring



Spring retaining ring



Key

Split pin

Figure 15: Indirect assemblies

In the oil industry, and particularly for maintenance, many different types of bolting are used. They will be considered in detail later in this course.

4. MATERIALS USED (in the oil industry)

4.1. BOLTING QUALITY CLASSES

The resistance criteria for the material are known as classes:

- class 4.6, 5.8, 6.8, 8.8, 10.9 & 12.9.

A min. and max. hardness is identified per class: the higher the figure, the higher the resistance.

Screws and nuts must not be combined any old how: a screw must not be used with a lower quality nut. The quality of the nut must be equal to or better than the quality of the screw.

Industrial bolting has "engraved" references.

Figure 16: Engraved references

4.2. MARKING OF SCREWS AND NUTS (I.S.O. 3506)

Markings are mandatory!

Corrosion-proof steel nuts and screws must be marked as follows:

Screws with hexagonal heads, cylindrical hollow hexagonal heads, and 6 lobe heads must be marked for nominal thread diameters of M5 or higher.

Figure 17: Marking of screws and nuts

HR (or HV) > high resistance (HR: French standards, HV: German standards)

10.9 > quality class

WTN > manufacturer identification

4.3. MATERIALS

4.3.1. The main materials used

Steels are alloys of iron and carbon (less than 2%).

Two main families are often defined: non-alloy steels and alloy steels (chemicals other than carbon are added to the iron: stainless steel).

Non-alloy steels >> Steels with low-carbon content. These are the most frequent types of steels.

Alloy steels >> 2 types of alloy steels exist

- Low alloy grade: the added element will not exceed 5%, these are used for applications requiring high levels of resistance.
- High alloy grade: the added element represents 5% or more, used for very specific usages (aeronautical sectors, bearings).

Iron and iron alloy

- Steel
- Stainless steel
- Cast iron

Non-ferrous alloys and metals

- Bronze
- Copper
- Brass
- Aluminium

4.3.2. Steel

Steel is an iron alloy with less than 2% in carbon content. It can be listed on the basis of carbon content. Steel with high carbon content will be used for its extra hardness, while steels with lower percentages of carbon simplify working, and are more malleable.

4.3.3. Alloy steels

Many alloying elements are used in the production of alloy steels. They have an effect on their structure and modify certain of their properties.

The most frequently incorporated elements are:

- Silicon
- Manganese
- Nickel
- Chrome

Followed by:

- Molybdenum
- Tungsten

- Vanadium

And, less frequently, for certain specific applications.

- Aluminium
- Titanium
- Niobium
- Cobalt
- Copper
- Boron
- Sulphur
- Phosphorus
- Nitrogen

4.3.4. Stainless steels

Stainless steels resist many corrosive environments.

Many grades of so-called "stainless" steels exist and are designated as "304", "304L", "316N", etc. corresponding to the different compositions and processes. Each type of steel corresponds to a certain type of environment, and their use in other environments could have very serious consequences.

Chrome is the key alloying element in all these steels as it ensures their "stainless" property.

Corrosion of stainless steels

Heat treatment is often a decisive factor in resistance to corrosion for stainless steels.

Worth remembering

Inter-granular corrosion >> Routing between the metal micro-crystals, leading to disintegration (composition of the steel).

Corrosion pits >> accidental presence of metal dust forming an electrochemical cell in humid environments (different of potential). The surface of the steel rusts. An acid environment or with high oxidisation can cause the same effects.

Stress corrosion >> result of the combined action of a mechanical stress and an aggressive environment. Highly dangerous for use? Leads to the appearance of cracks.

Conditions to be satisfied to encourage resistance to corrosion

Avoid any non-essential contact between stainless steel components and other metal or other materials.

It is clearly preferable to avoid "combining" metals, to prevent the electrochemical corrosion which would inevitably appear.

We will return to corrosion in the chapter on loosening problems

5. DIMENSIONS AND GEOMETRY

5.1. MOST FREQUENT SCREW DIAMETERS

The most frequent diameters for metric threads range from 1.6mm to 64mm.

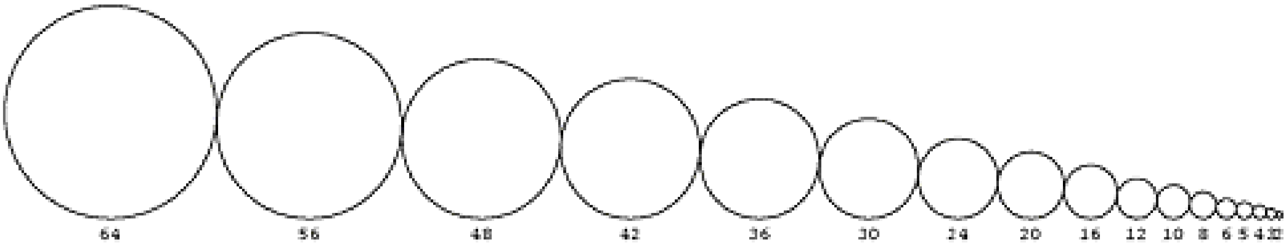


Figure 18: Most frequent screw diameters

With **Whitworth** (BSW or BSC), **API & NPT** threads, the screw size varies from 1/8 inch to 4 inches (standard)

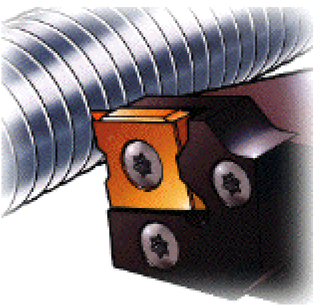
5.2. BOLTING DESIGN

5.2.1. Design of screws

THE PROFILE OF A SCREW IS KNOWN AS A THREAD

5.2.1.1. Machining of threads

The metal is cut by a rapid tool of superior hardness in several successive passes. The thread profile is determined by the shape of the cutting tool.



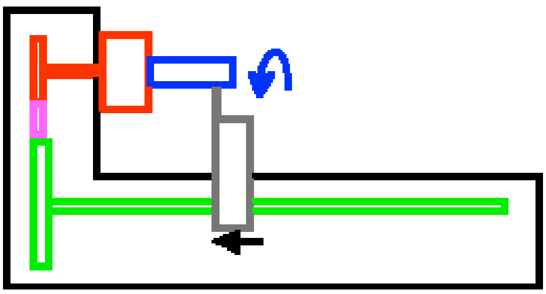


Figure 19: Machining of threads

The thread pitch is obtained by synchronising the advance of the tool carrier with the rotation of the machined part (gear ratio between the main screw and the rotation of the mandrel per rotation).

5.2.1.2. Roll bending of threads

With this technique, the rollers (shaped with the counterpart of the desired thread) are pressed on both sides, driven by the machined part, and gradually the part will acquire the shaping until reaching its final shape.

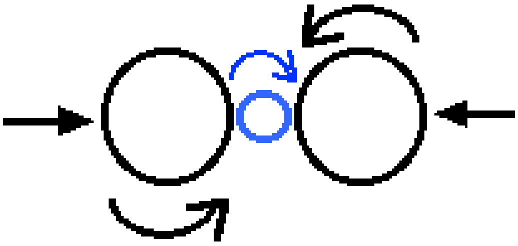


Figure 20: Roll bending of threads

5.2.1.3. Making the right choice

Obtaining a thread shape by deformation (roll bending) has the advantage of maintaining and reinforcing the "fibre structure" of the substance, thereby improving mechanical resistance and anti-fatigue/wear properties (stain hardening (>> **stress causing irreversible deformations).**

Certain applications such as vacuum technologies and ultra cleanliness imply a preference for machined threads as the roll bending process can generate the inclusion of impurities.

We could also mention the repair solution, using a die to thread a metal stem, or to refresh a damaged thread.

5.2.2. Design of nuts

An internal thread is the complementary half to a screw or threaded stem. This is a smooth hole in which a thread has been passed.

The hole in the bolt with its internal thread is generally tapped (or capped).

Figure 21: Dies and taps

The tapping of a hole requires the application of two principles:

- Turning >> internal threading tool covering a propeller along the axis of the hole.
- By screwing a tap in the smooth hole.

THE PROFILE OF A NUT IS KNOWN AS AN INTERNAL THREAD

5.2.3. Design of washers

Several types of washer design are possible: the most frequent are:

- Machining>> bar turning (machining of parts, in small, medium-sized and large series on traditional or digitally controlled lathes).
- Stamping (stamping is a manufacturing technique enabling the creation of an object from a thin sheet of foil).

5.3. DESIGNATION OF SCREWS AND NUTS

Reminder >> Screw + Nut = Bolt

Characteristics of screws and nuts, designations

E.g. for a H M x 1.5-50 Class 5.6 screw with a H M 10-50 Class 5.6 nut.

- H >> hexagonal head
- M >> ISO metric thread
- 10 >> diameter 10
- 1.5 >> 1.5mm pitch
- 50 >> screw length excluding the head
- class 5.6 >> quality

5.4. DIFFERENT SHAPES OF SCREW HEAD

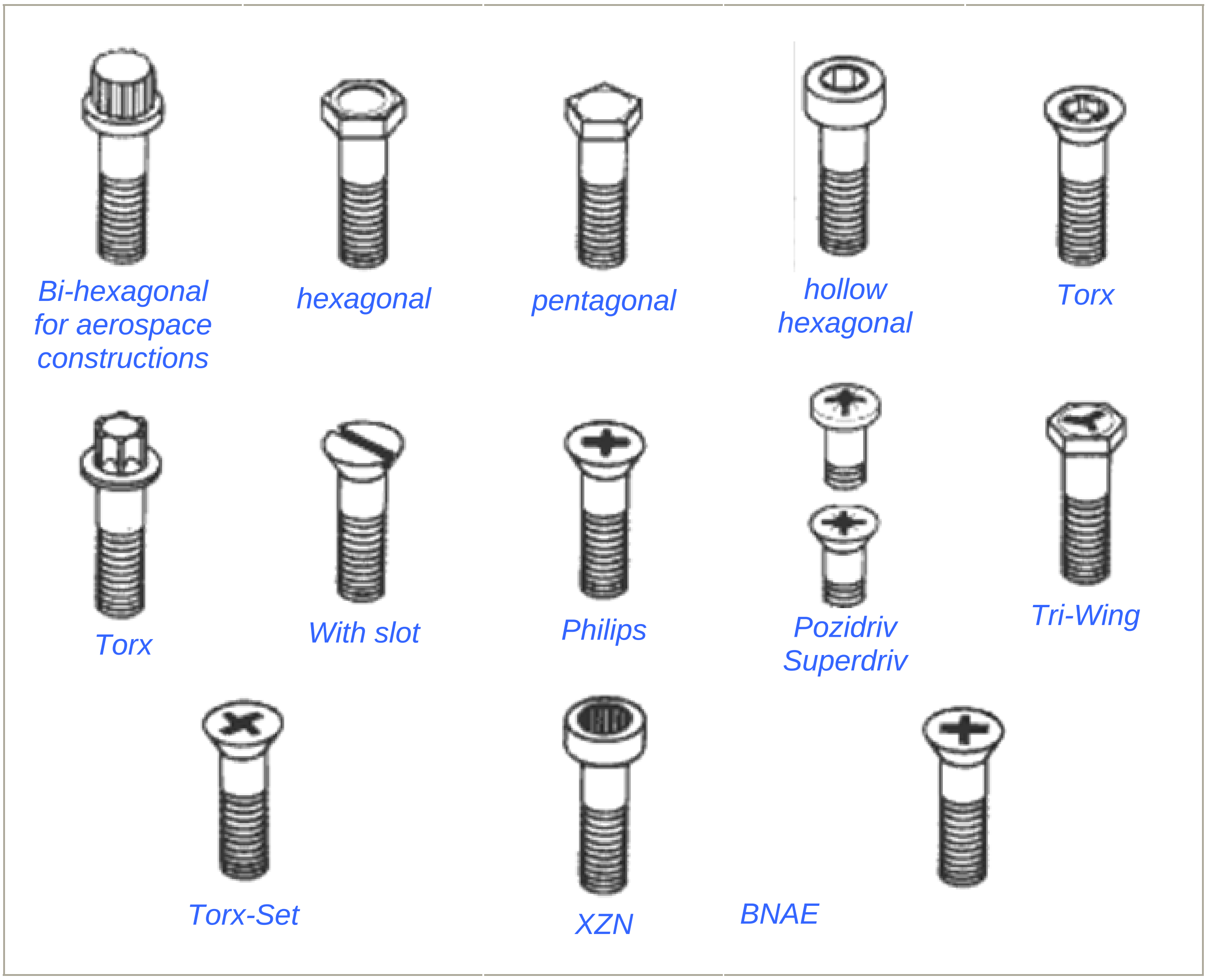


Figure 22: Different shapes of screw head

We will now consider the most frequently used types of screws.

5.4.1. Hexagonal head screw H

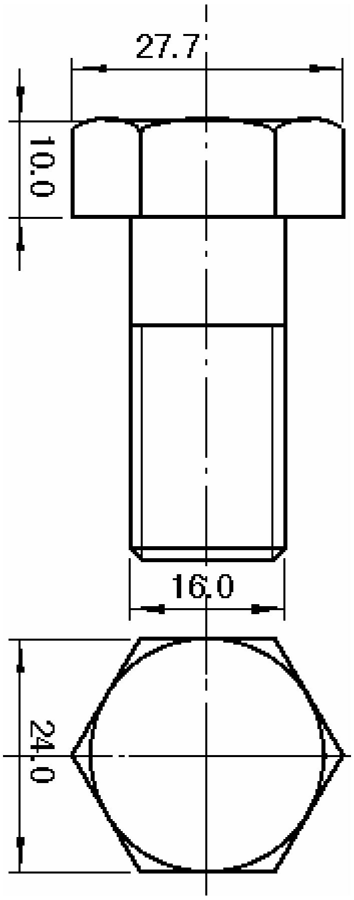
This type of drive is widely used due to its excellent transmission of torque.

ISO 4014 hexagonal head

Table of hexagonal screw head dimensions

d	3	4	5	6	8	10	12	16	20
Pitch	0.50	0.70	0.80	1.00	1.25	1.50	1.75	2.00	2.50
key	5.5	7	8	10	13	16	18	24	30
h	2.0	2.8	3.5	4.0	5.3	6.4	7.5	10	12.5

Pitch: Standard pith
Key: Key size
h: height of the screw head
***NB**: dimensions in mm*



Screw lengths are systematically indicated "excluding the head". To obtain the total length of a screw, add the height of the head to its length.

ISO 4014 defines partially threaded screws with H heads, and ISO 4017 defines the same screws with threading along the entire stem.

Figure 23: ISO 4014 hexagonal head

5.4.2. Countersunk head screw HC

This type of drive is less used due to its mediocre transmission of torque.

Table of hollow countersunk hexagonal screw head dimensions

d	1.6	2	2.5	3	4	5	6	8	10	12	16	20
ø	3.5	4.4	5.5	5.5	8.4	9.3	11.3	15.8	18.3	22.5	30	38
key	0.9	1.3	1.5	2	2.5	3	4	5	6	8	10	12

Ø >> screw diameter (pitch Ø)
Key >> key dimension
NB >> dimensions in mm

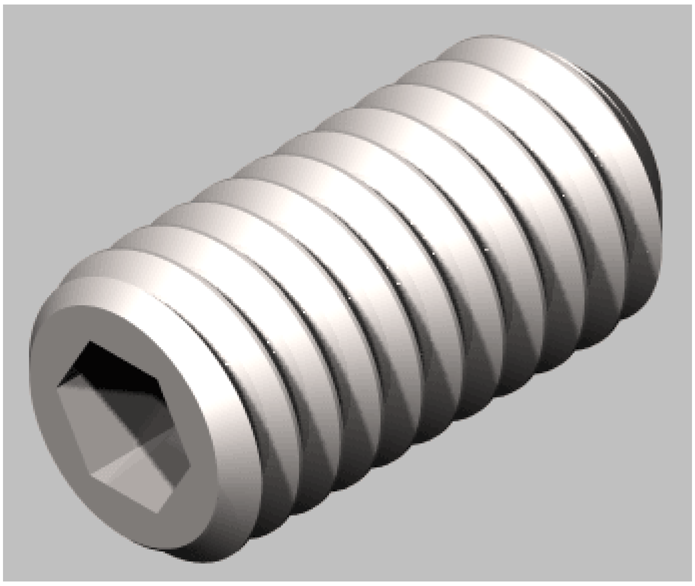


Figure 24: Countersunk head screw HC

The length indicated systematically corresponds to the total length of the screw.

ISO 10642 defines hollow hexagonal (HC) screws

5.4.3. Hollow hexagonal head screws CHC

This type of drive is widely used due to its excellent transmission of torque, despite lower performance levels than H head screws.

Advantages in terms of dimensions + no sharp edges.

Hollow cylindrical hexagonal head

Table of hollow cylindrical hexagonal screw head dimensions

d	1.6	2	2.5	3	4	5	6	8	10	12	16	20
ø	3	3.8	4.5	5.5	7	8.5	10	13	16	18	24	30
key	1.5	1.5	2	2.5	3	4	5	6	8	10	14	17
h	1.6	2	2.5	3	4	5	6	8	10	12	16	20

Ø >> screw head diameter
Key >> key dimension
h >> height of the screw head
NB >> dimensions in mm

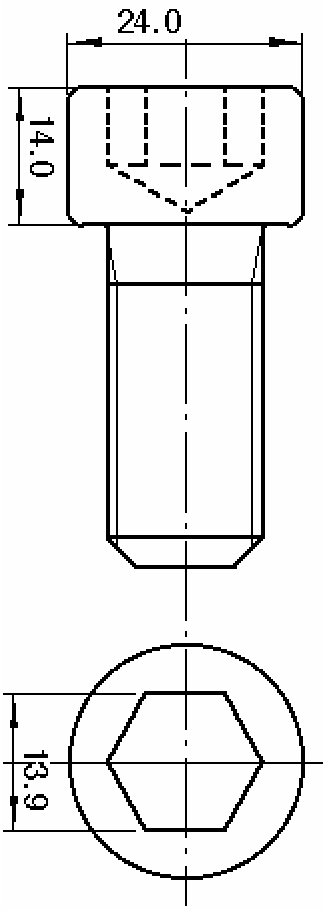


Figure 25: Hollow hexagonal head screws CHC

5.5. DETERMINING WHERE TO POSITION THE SCREW

<u>How to determine where to position the screw</u>

Exception when you use standard bolts, where you need to make sure you select a nut class which is equal to or higher than the screw class (e.g.: class 10 nut for a class 10.9 screw), all elements must be accounted for and specified when designing the connection.

- it is essential to have enough material to ensure the resistance of an internal thread
- the length of the thread in contact must be defined
- cap or tapping internal thread, some points must not be forgotten

5.6. MATERIAL REQUIRED AROUND THE HOLE WITH THE INTERNAL THREAD

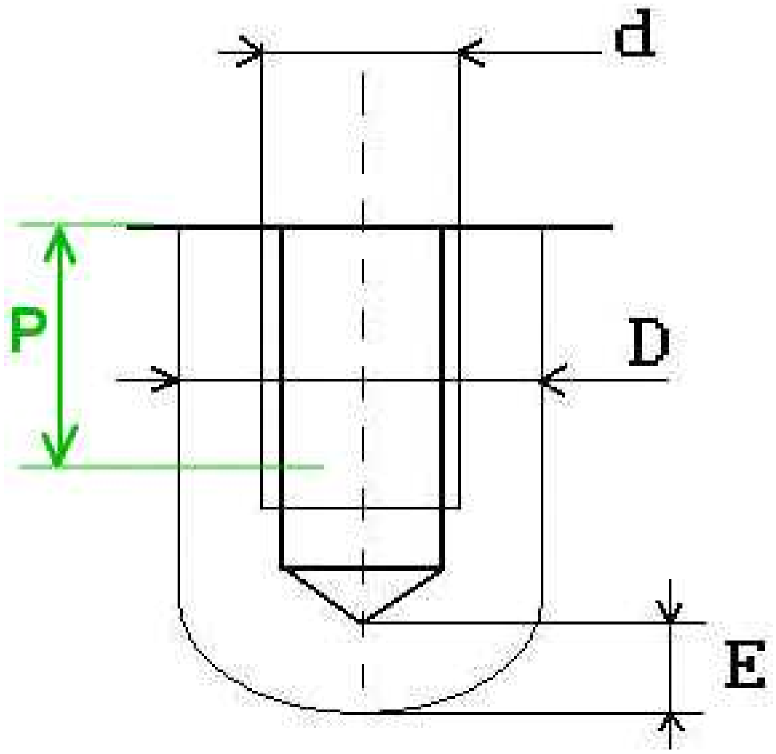


Figure 26: Material required around the hole with the internal thread

This is not a problem if you are certain to create the hole in a solid material.

However, this is a problem if material is limited, as would be the case with the assembly of 1/2 light alloy carters. Overthicknesses are arranged in the foundry wall to allow for the optimal fitting of screws.

You must also ensure the quality of the material in the hole area: absence or limited presence of porosities bared during machining.

- no *Helicoil: **D = 2 * d**
- with *Helicoil: **D = 2 *(d + pitch)**
- **E = (D - d) / 2**

** Helicoil = helical thread insert*

5.7. DEPTH OF FITTING AND MACHINING TOLERANCES

The length of the fitting (or the length of the screw thread in contract) is calculated on the basis of the section of thread subject to shearing and the section of the screw hub subject to traction forces.

It is determined by solving the equation: Shearing resistance = traction resistance.

The thread tolerance class applies here: The more limited the tolerance, the larger the section sheared and the better the resistance of the internal thread.

3 adjustment classes have been defined for ISO threads:

- "Precise" adjustment (**5H/4h**) for special cases where careful precision is required for the pitch and thread.
- "Mean" adjustment (**6H/6g**) for routine applications. This adjustment is applied for screws with diameter < 16mm (grade A) and diameter >16mm (grade B).
- "Free" adjustment (**7H/8g**) if assembly must be executed in a difficult environment even if the threading has been deformed (impact, etc.) or in the presence of impurities.

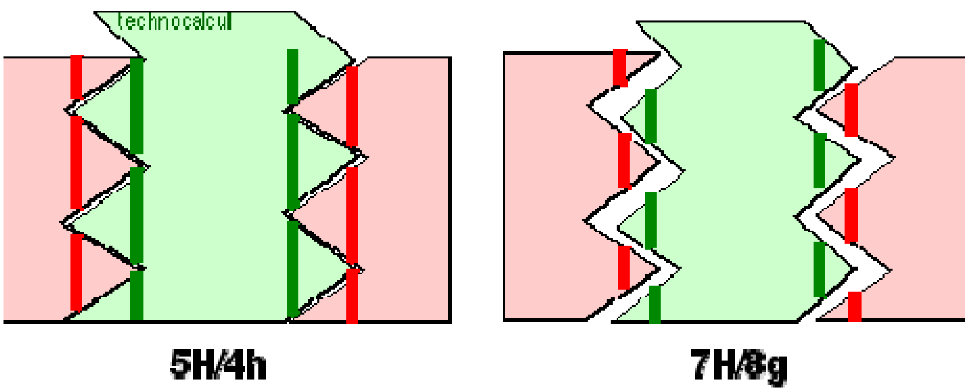


Figure 27: Adjustments

The value of the adjustment to the screw/nut pair will affect the section sheared and the resistance of the connection.

Use				Shaft	Bore				
					H6	H7	H8	H9	H11
Separate mobile parts	Part which requires extensive clearance for operation (expansion, incorrect alignment, long distance, etc.)			**c**				9	11
				d				9	**11**
	Ordinary case of rotating parts or parts sliding in a ring or bearing raceway (satisfactory greasing guaranteed)			**e**		7	**8**	**9**	
				f	6	6 7	**7**		
	Part with precise guiding for small movements			**g**	5	**6**			
Separate fixed parts	Dismantling and re-assembly possible without damage to the parts	The adjustment cannot transmit effort	Manual fitting possible	**h**	**5**	**6**	**7**	**8**	
				js	**5**	6			
			Fitted using a mallet	**k**	**5**				
				m		**6**			
	Dismantling not possible without damage to the parts	The adjustment can transmit effort	Fitted using a press	**p**		**6**			
			Fitted using a press or by expansion (check that the stress imposed on the metal do not exceed the elastic tolerance)	**s**			7		
				u			7		
				x			7		
				z			7		

Table 1: Main adjustments applied

6. STANDARDS

6.1. WHY DO WE NEED STANDARDS?

In view of the multiplication of technological innovations in the last 30 or more years, all products supplied by manufacturers, publishers, integrators or consultancy firms include technological components of heterogeneous origin.

To ensure that the aggregate products work, all components need to have a common denominator to enable all parties to recognise the contributions of the other parties.

These are product standards and it is essential to be familiar with these standards to be able to create solutions and understand the future developments of techniques.

All bolts (screw + nut assembly) correspond to standardised characteristics defined as follows:

- Screw (male part): its nominal diameter, i.e. the diameter at the crest of the thread, and the thread pitch.
- Nut (female part): its major diameter, i.e. the diameter at the root of the thread (or the root of the internal thread), and its pitch.

The pitch is the distance between 2 thread crests (or 2 thread roots)

ISO (*International Standard Organisation*) threads, for the organisation having defined them, are now universally used throughout the world.

Great Britain and the USA switched to this standard many years after other countries due to their preference for imperial units.

However, before the ISO thread came into being, another standard existed: the **SI** thread (International system of units).

6.2. THE ORGANISATION

Standardisation is now international, or at least European, while the national standards are slowly disappearing.

The countries vote on new standards.

Each country has therefore organised its structures in view of this system.

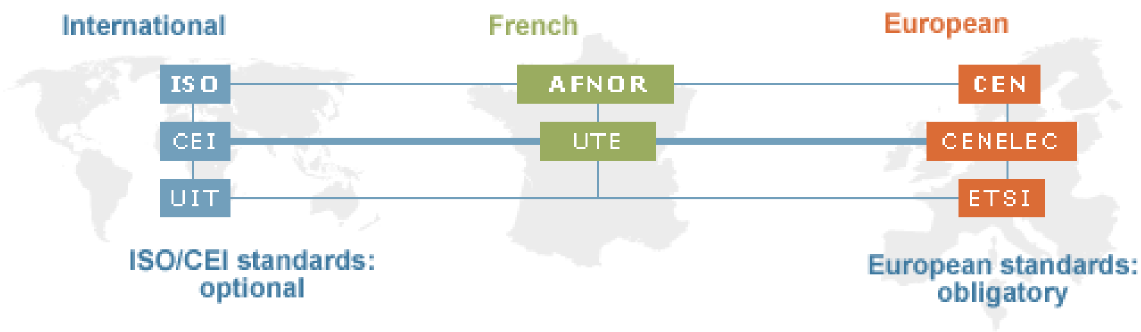


Figure 28: Organisation of standardisation

AFNOR: French association for standardisation

The AFNOR organises this system in France. Its responsibilities are as follows:

- Identification of standardisation requirements
- Drafting of strategies for standards
- Organisation of the standardisation system
- Coordination of standardisation programs
- Mobilisation of partners
- Participation in European and International standardisation systems
- Authorisation, distribution and promotion of standards
- Development of national certification for conformity with standards

6.3. LIST OF STANDARDS RELEVANT TO SCREWS AND SIMILAR

<u>**Main ISO standards**</u>

21.040: threads

- 21.040.01 >> threads in general
- 21.040.10 >> metric threads
- 21.040.20 >> imperial threads (including Whitworth threads)
- 21.040.30 >> special threads (miniature, gas)

The detailed list of standards will clearly not be mentioned in this course. It would serve no purpose to list these standards one by one as when bolts are used on sites, the bolts have been carefully ordered by a service specialised in the purchase of these products.

However, great caution is required when using bolts. This particularly applies when selecting screws and nuts (material, class).

7. TIGHTENING

The aim of controlled tightening is to:

- Avoid breaking the bolt or one of the assembled parts.
- Prevent sudden loosening.
- Regularly tighten sealing surfaces (Deformations, leakage).
- Check the clearance between the different moving parts is satisfactory.
- Ensure optimum safety for operators and end users.

7.1. TIGHTENING TO TORQUE

This is undeniably the most widely used method. Its main benefit lies in the simplicity of its application.

7.1.1. With indications

What are we aiming for when tightening a screw to hold part A assembled to part B? We are aiming to hold the two parts together sufficiently to prevent them from moving independently, even in case of heat expansion or shrinking, vibrations, stress or corrosion.

The parts may therefore continue to fulfil the mechanical function for which the assembly was designed. At the same time, over-tightening should be avoided.

You might crush one of the 2 parts, or even both parts, or stretch or break the screw. There is little risk of detaching the thread as ISO threads are designed for the main screw stem to break off first (it's easier to repair).

Tighten the screw only to the required torque.

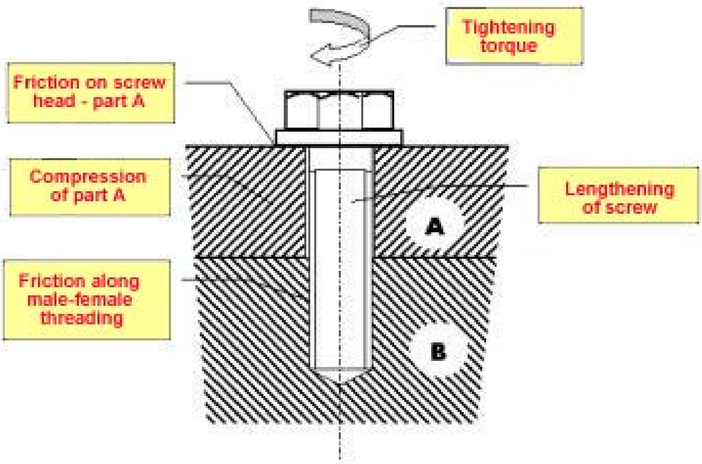


Figure 29: Tightening to torque

Torque is applied to a screw during tightening.

This torque is initially very low, and can be applied using your finger tips.

This enables you to fit the screw until the bottom of the head comes into contact with part **A**. From this point, the torque will increase substantially, and you will need a tool to apply it.

What is torque used for?

Torque has four useful effects:

- Overcome friction appearing between the lower surface of the screw head and part A.
- Overcome friction appearing between the screw thread and the internal thread in part B.
- Pull on the screw to stretch it.
- Crush part A to compress it and maintain a seal if applicable (presence of a seal between A and B).

Effects 1 & 2 prevent the screw from unscrewing accidentally. However, during screwing, these effects have a negative effect. If the torque applied does not vary, effect 3 will have more or less impact depending on the extent of the friction. If the screw is lubricated, friction will be reduced. As a constant torque is applied, effect 3 will increase.

Effect 3 takes advantage of the elasticity of the screw to compress part A and hold it against part B, even if dimensions vary. The higher the torque, the more the screw is subject to traction, and the less the two parts A & B will be able to detach due to vibration, temperature variations, or external forces.

Effect 4 is complementary to effect 3. If the screw is much more resistant than part B, the overall effect will be to crush part B rather than extend the screw. And vice versa.

This is why manufacturers indicate the torques to be applied during re-assembly in their technical notices. These indications must be carefully followed.

Notices never indicate the condition of the parts: condition of the surface of part A under the screw head, lubrication of the thread. What should you do? By default, assume that the torques indicated apply for new parts, as they leave the manufacturing line (clean, no lubrication, zinc coated/ bichromate plated (generally speaking)).

Worth remembering:

- If the screw is lubricated, you will apply more traction than for the identical torque applied to a non-lubricated screw.

7.1.2. No indications

If you do not have access to a notice, apply the following torques, for class 8.8 screws (the most frequent class):

Torque in Nm	**Adequately lubricated zinc coated screws**	**Black or zinc coated screw. little lubrication**	**Dry screw, with or without coating**
	Friction coeff. 0.10	Friction coeff. 0.15	Friction coeff. 0.20
6 screw	7.5	9.5	11.1
8 screw	18.2	23	27
10 screw	36	46	53

You can see that, the less the screw is lubricated, the more torque must be applied as this torque is mainly used to overcome friction.

7.2. CROSS TIGHTENING

7.2.1. Tightening method for screws arranged in circles

7.2.1.1. For 4 screws arranged in a circle

The screws are represented by figures **1 / 2 / 3 / 4**

- Tighten the screws by hand to a maximum
- Tighten (torque wrench if the torque is known, otherwise refer to cf. § 7.1.2) screw 1
- And then screw 2
- And then screw 3
- And then screw 4

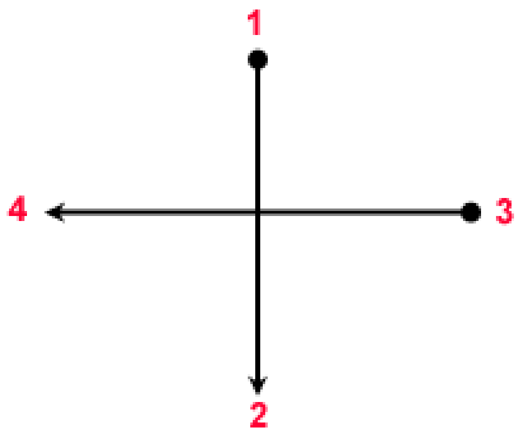


Figure 30: Cross tightening for 4 screws in a circle

7.2.1.2. For 6 screws arranged in a circle

The screws are represented by figures **1 / 2 / 3 / 4 / 5 / 6**

Apply the same procedure as for 4 screws

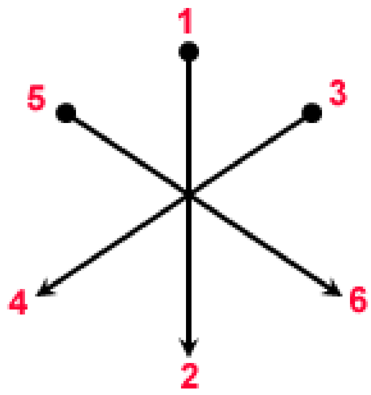
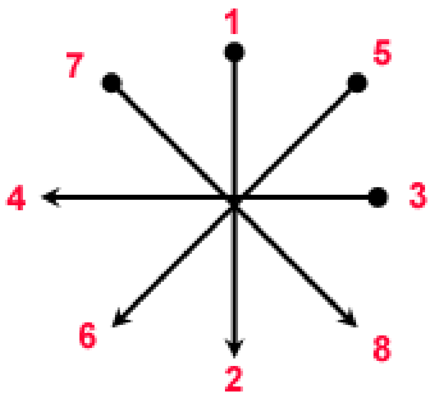


Figure 31: Cross-tightening for 6 screws in a circle

7.2.1.3. For 8 screws arranged in a circle

The screws are represented by figures **1 / 2 / 3 / 4 / 5 / 6 / 7 / 8**



Apply the same procedure as for 4 or 6 screws

Figure 32: Cross tightening for 8 screws in a circle

This tightening method is applied at flange level (junction of 2 pipes, pipes on tank, filter cover, etc.)

7.2.2. Tightening method for screws arranged in rectangles

Screws are systematically represented with figures

7.2.2.1. For 4 screws arranged in a rectangle

The screws are represented by figures **1 / 2 / 3 / 4**

Apply the same procedure as for 4 screws arranged in a circle.

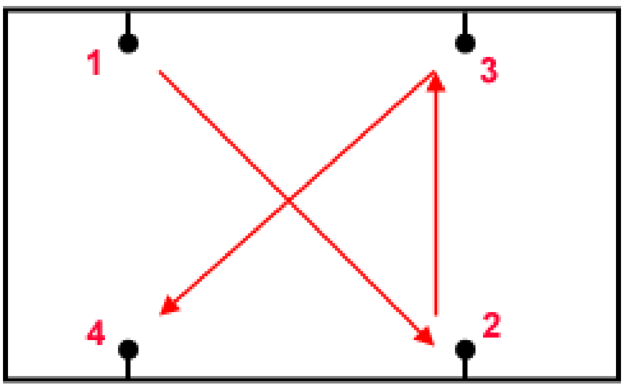


Figure 33: Tightening of 4 screws arranged in a rectangle

7.2.2.2. For 6 screws arranged in a rectangle

The screws are represented by figures **1 / 2 / 3 / 4 / 5 / 6**

Apply the same procedure as for 6 screws arranged in a circle.

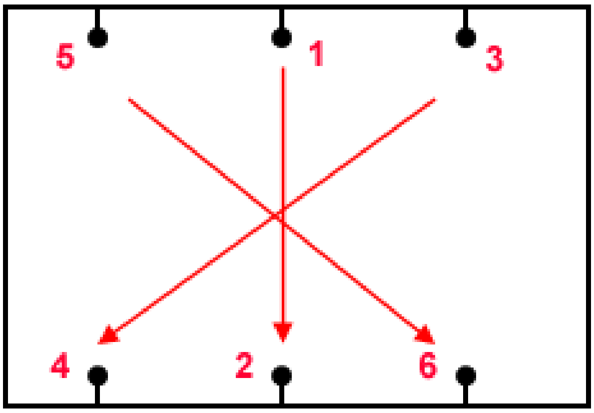
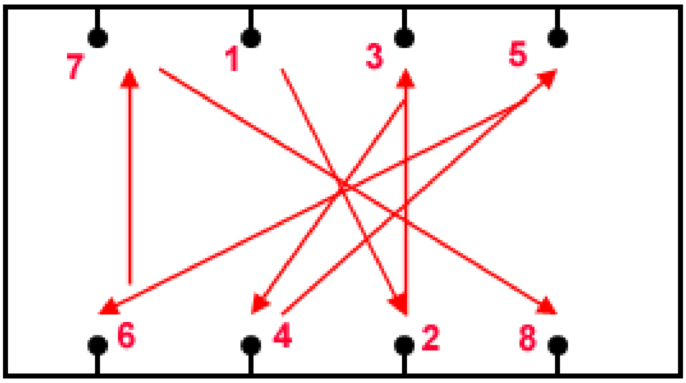


Figure 34: Tightening of 6 screws arranged in a rectangle

7.2.2.3. For 8 screws arranged in rectangles



The screws are represented by figures **1 / 2 / 3 / 4 / 5 / 6/ 7 / 8**

Apply the same procedure as for 4 and 6 screws arranged in a circle.

Figure 35: Tightening of 8 screws arranged in a rectangle

This tightening method is applied at turbine stator level, combustion engine cylinder head level, etc.

Now that you know the methods for up to 8 screws, it will be easy to tighten a higher number of screws.

>> To ensure good quality tightening, you will need to apply the torque wrench several times until you reach the torque recommended by the manufacturer <<

7.3. ANGULAR TIGHTENING

This method is used for tightening requiring very high torque (screws with large diameters >> cylinder heads on large engines, turbine stators, etc.)

After having tightened the screws using a torque wrench, the manufacturer recommends completing tightening using the angular tightening method.

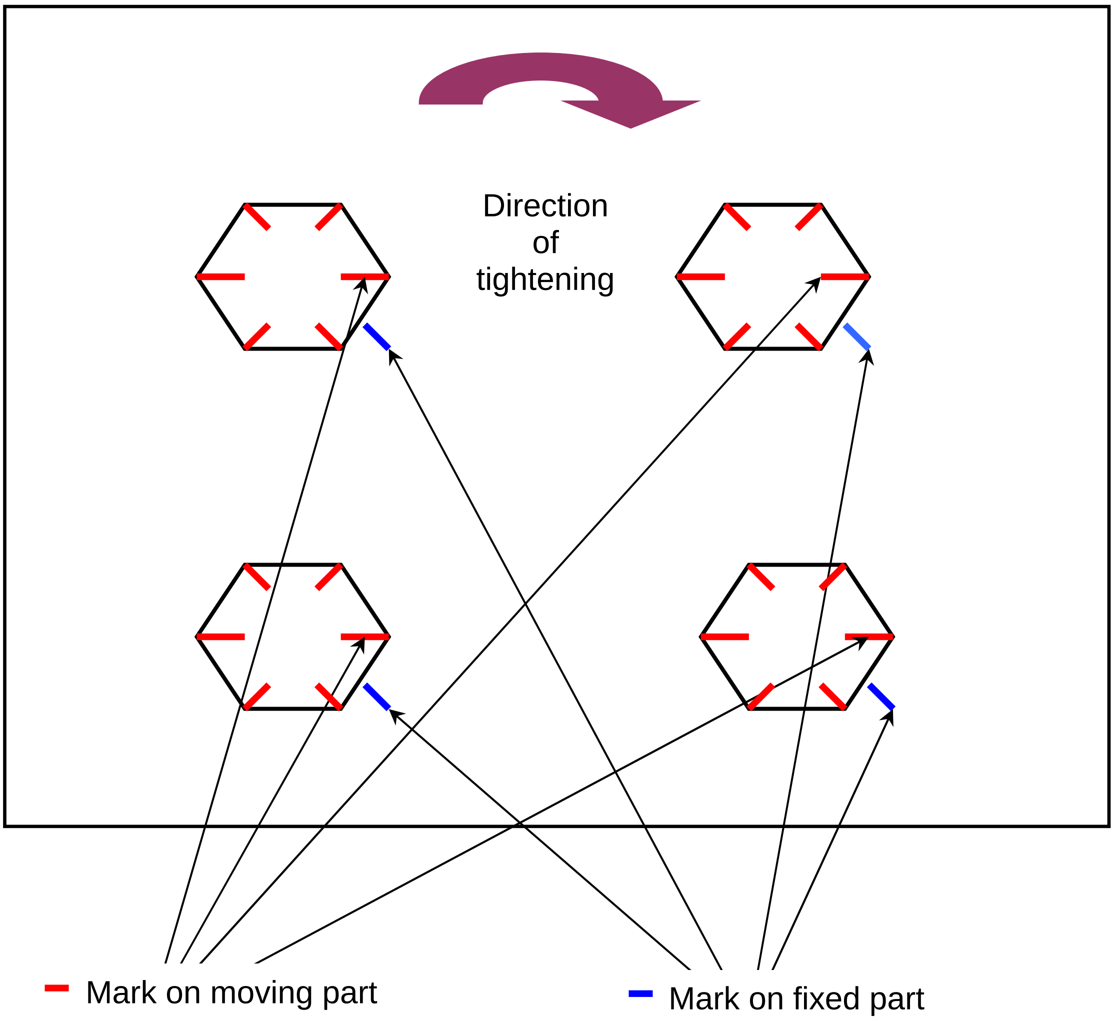


Figure 36: Diagram showing angular tightening

To this end, draw a line in front of each angle of all screw heads (marker pen, paint, etc.) and one line on the fixed part (part to be tightened) opposite each screw.

- Start by tightening with an appropriate wrench (in principle, this will be a tube wrench or a square equipped with a socket), and use an extension if necessary (tube) to increase the force of this wrench.
- Apply the principle of cross tightening.

- Repeat the procedure as often as indicated by the manufacturer.

This tightening will produce a very high screw torque.

Simply match the mark on the mobile part (screw head or nut) to the mark on the fixed part (part to be assembled).

7.4. TIGHTENING METHODS

7.4.1. Tightening using hydraulic tension adjusters

Use a pre-loaded actuator: this is a short-travel jack.

The main section of the jack will press against the assembly.

A socket screwed on the threaded end of the screw to be tightened is placed on the piston.

The pressure corresponding to the desired tension is applied using the hydraulic unit or a hand pump.

When the pressure is reached (read the pressure gauge), the nut is effortlessly screwed until it comes into contact with the fixed part.

The jack can be released by exposure to atmospheric pressure.

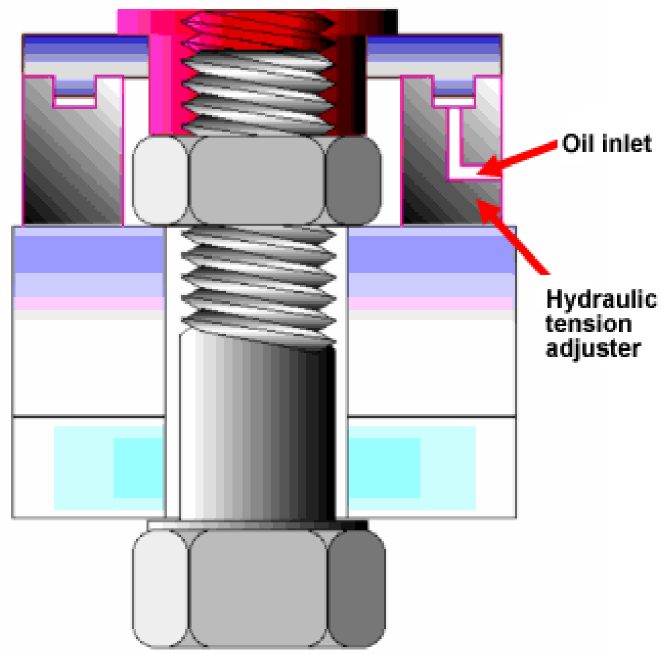


Figure 37: Tightening using hydraulic tension adjusters

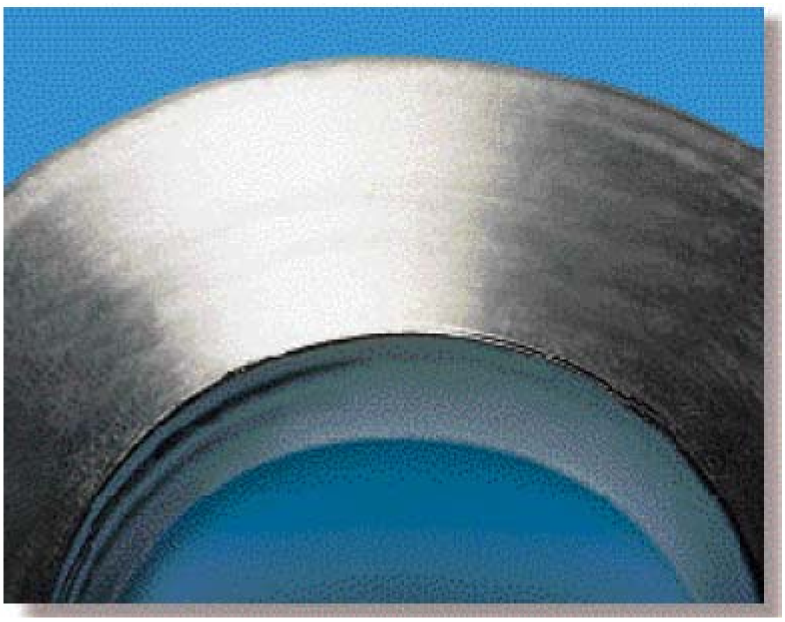
Advantages of tightening using hydraulic tension adjusters

- No bending stress
- Very accurate
- Easy to use
- Wide range of diameters
- Wide range of materials

- No damage to parts
- Easy to loosen
- Simultaneous tightening possible

The tightening method using hydraulic traction enables the precise determination of the level of tightening stress in terms of the elastic tolerance of the material.
This is very important for the quality of the assembly as the nearer the tightening stress of a bolt is close to its elastic tolerance:

- the better the resistance of the assembly
- the longer the life cycle of the bolt subject to cyclic forces



Surface condition of a part tightened with a hydraulic tension adjuster.

As we can see, the surface in contact with the tightening device has not been damaged.

Figure 38: Surface condition of a part tightened with a hydraulic tension adjuster

7.4.2. Tightening with an extension

This technique requires the use of an extension (metal tube) on the end of the tightening tool of a length which is equal to or more than the length of the tightening tool and which will increase the torque.

This tightening method is used in the heat industry (tightening of clamps on steam collectors), and also for angular tightening.

7.4.3. Tightening with an impact wrench

Instead of using a traditional tightening tool (tube wrench, square and tightening socket, etc.), we will use an impact wrench.

Simply apply this wrench to the screw head, hold in place, and hit with a weight.

This method is used to tighten nuts on pressure sealed boiler doors for example, or screws on large diameter pipe clamps.

Figure 39: Impact wrench

This method will be used for large diameters.

Surface condition of a part tightened using the cross method, with an impact wrench and an extension. It is clear that the surface has been damaged.

After several dismantling operations, the surface in contact with the screw will be irrevocably marked or totally damaged.

Figure 40: Surface condition of a part tightened using the cross method, with an impact wrench and an extension.

8. PROBLEMS FACED

8.1. PROBLEMS RELATED TO LOOSENING

8.1.1. Loosening, a risk factor

Loosening screwed connections is one of the main causes of failure for mechanical systems.

With the reduction - or even the loss - of the torque, the threaded elements are subject to significant variations in forces.

Many resources are designed to prevent loosening: lock nut, safety washer, lock washer, locking nut, rotation check, thread lock, etc.

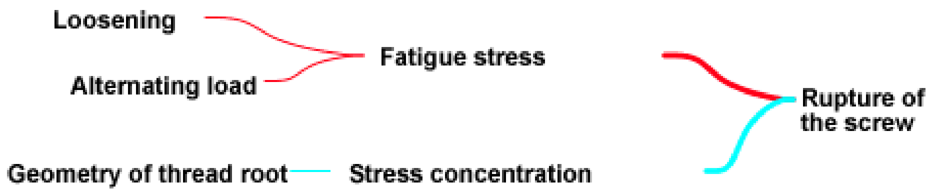


Figure 41: Loosening risks

8.1.2. Origin of the loosening

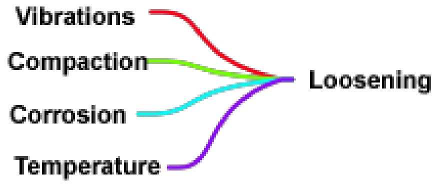


Figure 42: Origin of loosening

Impact and vibrations represent the main source of loosening, and their effects occur fairly rapidly.

Other causes such as compaction, temperature variations and corrosion have a slow and discrete, but identical long-term effect on screws.

8.1.3. Avoiding loosening (most widely used methods)

- Elasticity reserve (adapted material)
- Rotation check (braking)
- Surveillance (frequent checking of installations)
- The hardness and roughness of surfaces

Locking screws is one means of preventing them from loosening.

8.1.3.1. Mechanical locking

Lock nuts

Simply block the nut in contact with the washer with another nut. This is a widely used method.

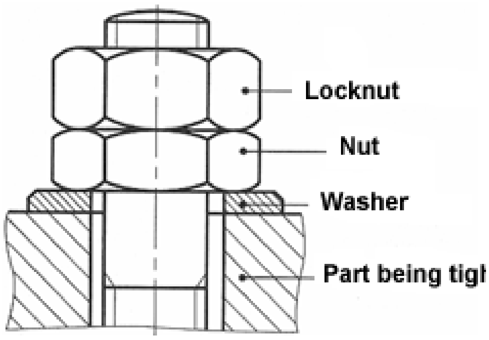


Figure 43: Lock nuts

Split pin

Figure 44: Split pin

Pin used with slotted nuts or traditional nuts blocking rotation.

In theory, these pins may not be re-used and must be replaced after each dismantling operation (as far as possible >> loss of mechanical resistance after several uses…)

In certain cases, these pins may be replaced with elastic Beta type pins which have the advantage of being re-usable.

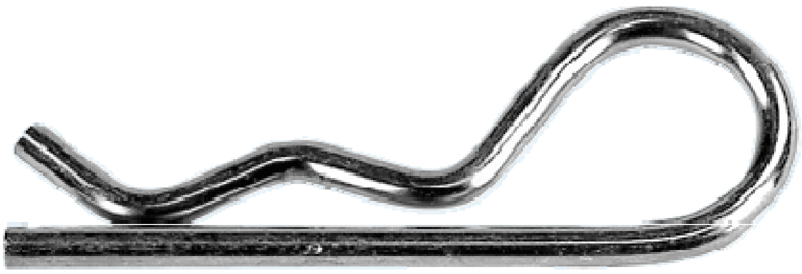


Figure 45: Elastic pin

Assembly method for split pins

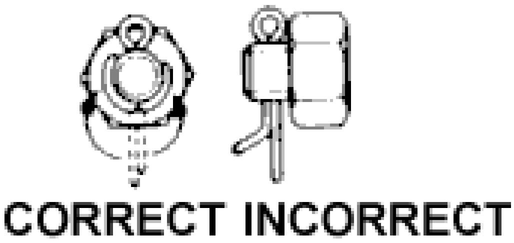


Figure 46: Assembly method for split pins (1)

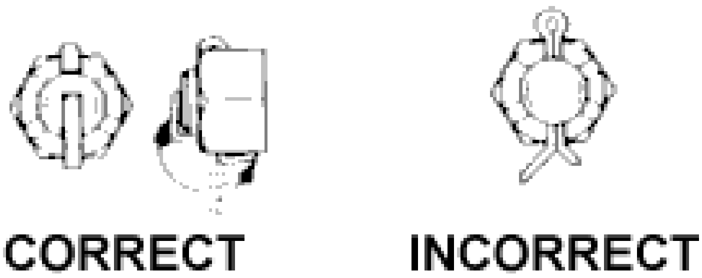


Figure 47: Assembly method for split pins (2)

As a general rule, the head of a split pin must be placed facing forwards or in the direction of operation (to avoid detachment due to contact with any object).

Figure 48: Example of the use of a split pin

8.1.3.2. Lock wire

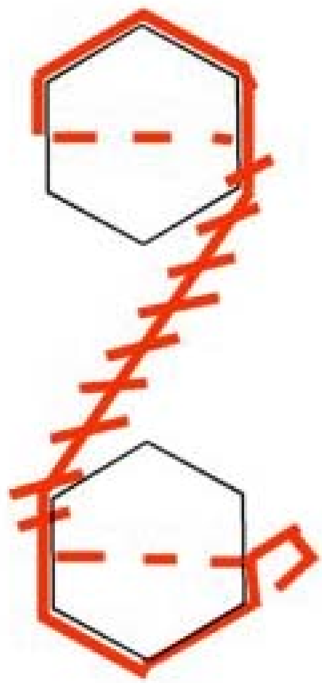


Figure 49: Lock wire assembly method

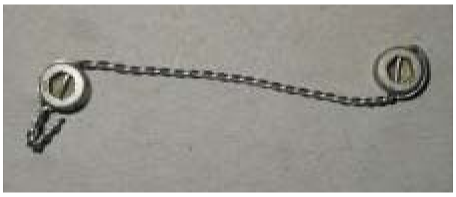


Figure 50: Example of the use of lock wire

8.1.3.3. Washers

Lock washers

Figure 51: Examples of lock washers

Lock washer

Figure 52: Example of a lock washer

Tooth lock washer

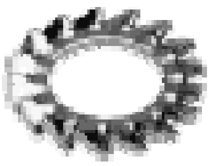


Figure 53: Example of a tooth lock washer

Drawbacks of a tooth lock washer:

Damage to the contact surface.

If a tooth lock washer corrodes, it gradually turns into dust (design problem) and will create clearance between the bolt and the part to be assembled >> high risk of loosening.

In addition, this type of washer will damage the surface in contact with it (design problem).

8.1.3.4. Locking nuts

Helicoil locking nut

Safety nut which is locked by the deformed section of a thread insert

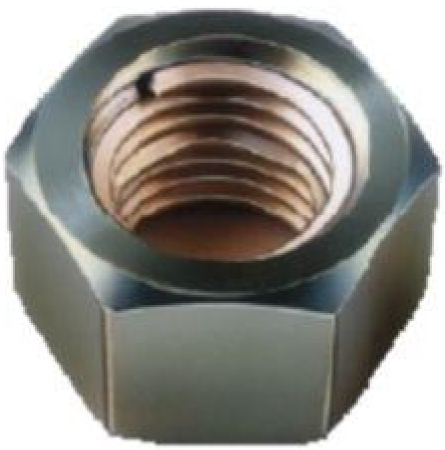


Figure 54: Helicoil locking nut

Nylon ring locking nut

Figure 55: Nylstop locking nut

Split nut

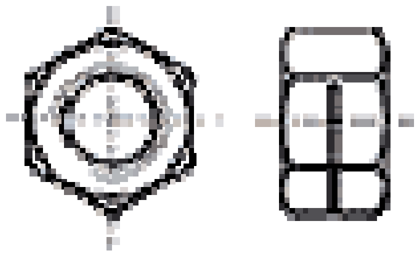


Figure 56: Split nut

Slotted nut

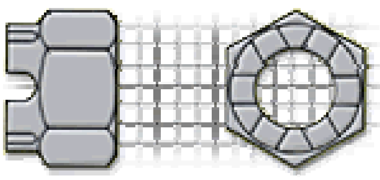


Figure 57: Slotted nut

8.1.3.5. Adhesives

Types of thread locks

Different types of thread locks exist:

***Weak thread lock**:* Moderate resistance, ideal for assemblies subject to low forces

- Resistance to vibrations
- T -5 to + 150 °C T
- Polymerisation time* = 12h00

***Normal thread lock**:* Average resistance, locks and seals threaded parts

- Excellent resistance to vibrations,
- T -5 to + 150 °C
- Polymerisation time* = 12h00

***Strong thread lock**:* Used to block and attach parts which will not be dismantled.

- Resists fluids and industrial gases.
- T -5 to +150 ° C
- Polymerisation time* = 12h00

***High-temperature strong thread lock**:* UV fluorescent, not soluble in water

Figure 58: Example of the application of a thread lock

Definition of polymerisation:

Polymerisation is a chemical reaction, which depends on time and temperature, and causes the resin to solidify definitively.

There is also another means of locking which is less frequent, but just as effective:

This involves the creation of a welding point between the screw head (or nut) and the part to be tightened (this clearly only applies if the 2 materials can be welded together). This method is little used.

8.2. PROBLEM DUE TO THE RUPTURE OF THE SCREWED CONNECTION

Several factors can cause a rupture:

- Over-tightening during assembly (incorrect handling, design error).
- Incorrect selection of materials.
- Material fatigue.
- Corrosion.

You must start by identifying the causes of the anomaly before starting repairs under all circumstances.

8.3. DETACHMENT OF THE INTERNAL THREAD

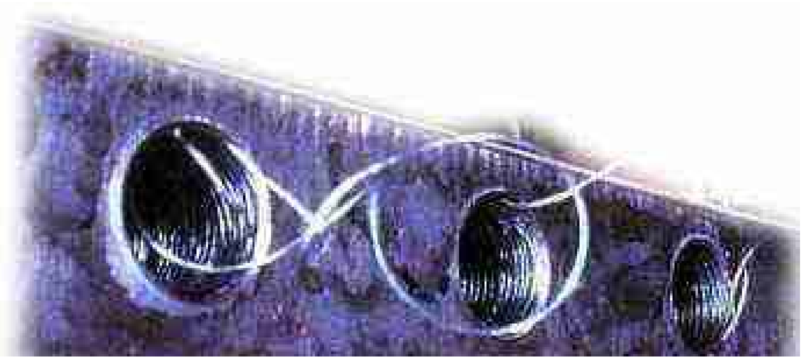


Figure 59: Detachment of the internal thread

Possible causes:

- Inadequate material quality.

- Too short thread (screw).
- The internal or external thread (or both) are not within their tolerance intervals.

This may be repaired thanks to the inserts. These are in fact thread inserts.
Several models exist:

"Helicoil" inserts: thread inserts consisting of wound wire with a trapezoidal section (these is the most frequently used).

Figure 60: Example of a Helicoil insert

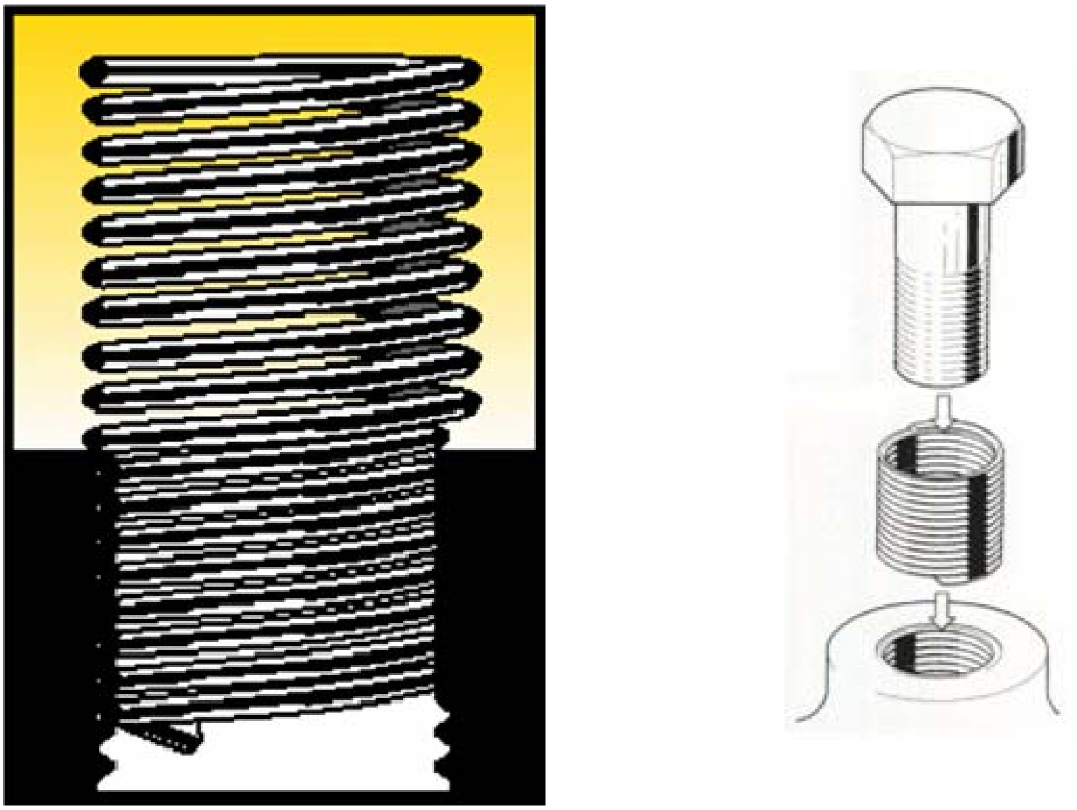


Figure 61: The principle of Helicoil inserts

This is the easiest (and quickest) method of repairing a damaged internal thread.

<u>Advantages of thread inserts:</u>

- Mechanical reinforcement of the internal thread
- Excellent resistance to vibrations
- Stainless steel insert > excellent resistance to corrosion

- Reduced thread wear
- Good resistance to temperatures

"Keensert" inserts: inserts machined into solid material. These inserts are slightly larger than the previous model. They stay in place once fitted.

Figure 62: Example of "Keensert" inserts

Inserts consisting of a wire are beneficial for definitive connections or if dismantling is exceptional. They may indeed be accidentally removed with unscrewing difficulties.

8.4. RUPTURE OF THE SCREW

Figure 63: Ductile rupture of a screw

Figure 64: Brittle rupture of a screw

Forces exceed rupture limits. The screw section starts to reduce and then suddenly breaks.

This type of damage is preferable: it is always easier to change a screw than to add an insert.

When selecting connection parameters, ensure that the internal thread (material resistance and length of fitting) is more resistant than the screw.

8.5. PROBLEMS RELATING TO CORROSION

Corrosion, in the general sense of the term, can be described as the deterioration of material by the surrounding environment.

In the atmosphere, in the presence of humidity and oxygen, steel becomes coated with a layer of iron oxide, known as rust.

AFNOR (NFT30 001) specifies that "the phenomenon of corrosion can be defined as the deterioration of the initial metal condition until the destruction of this condition due to the action of the ambient environment and due to any process which is not mechanical".

Corrosion is due to the action or the effects of corrosive substances or a corrosive environment.

The corrosion of metals and their different alloys prove their tendency to return to their natural state of ores under the effect of atmospheric agents. This phenomenon depends on the corrosive substance and the material concerned and the environment of the 2 elements.

Water has a significant corrosive effect on steel. This role is activated by mineral salts and other chemicals contained in water (sea water is far more corrosive than fresh water), but also by temperature, PH, and the presence of oxygen, etc.

Factors in corrosion have various origins:

- Physical, due to erosion by wind, sand, or the result of an impact, etc.
- Chemical, due to the presence of oxygen in dry atmospheres at high temperatures
- Biological, alterations relating to the development of micro-organisms (bacteria, mushrooms, algae, etc.)
- Electrochemical, corrosion develops in the presence of an electrolyte consisting of water, salt and oxygen, for example.

8.5.1. Aqueous corrosion

Corrosion refers to the alteration of a substance by its environment. The most known examples are the chemical alteration of metals in water, with or without oxygen, such as rust on iron or steel, or the formation of verdigris on copper and copper alloys.

These alterations are due to several types of effect: the dissolution of metals in water, the creation of electrochemical cells, differential aeration or pitting.

Globally, aqueous corrosion is a phenomenon whose economical impact is substantial and which requires a wide range of protection for metals.

8.5.1.1. Galvanic corrosion

Galvanic corrosion is electrochemical corrosion caused by the formation of an electrochemical cell due to contact between two different conductive materials in an electrolytic environment. This results in the formation of a galvanic couple.

- The 2 materials must conduct electricity.
- The 2 materials must be different and in contact

The corrosion appears mainly in the assembly and connection areas.

The circuit must be closed, and be located in an electrolytic environment. A maritime environment is ideal (humidity +salt).

When two metals come into contact in a humid environment, a difference of potential will occur between the different metal points. The least noble metal will corrode and act as the anode. The second metal will act as the cathode and corrode last.

This is known as galvanic corrosion and causes significant damage.

You must therefore take great care when combining 2 different materials.

8.5.1.2. Concentration cell corrosion

This is very similar to galvanic corrosion. The difference is that the corrosion occurs on just one metal part. There is no assembly of 2 different metals.

This type of corrosion occurs if the composition of the environment varies. The electrochemical potential is determined by the environment/material couple, if one of the 2 varies and the potential varies.

If a part in a water jet has a cavity, the water in this cavity stagnates and its composition changes with chemical oxidation-reduction reactions. In parallel, the water outside of the cavity is renewed and maintains the same composition. An electrochemical cell may therefore occur between the cavity and the exterior of the part, causing accelerated corrosion.

A single part will behave in a different manner in stagnating water and moving water.

8.5.1.3. Corrosion due to differential aeration

Corrosion due to differential aeration occurs if a given material comes into contact with two environments with differing oxidisation content.

To give an example, this is the case for ship hulls. The layer of water near the surface contains more oxygen than the deeper layers. Corrosion may occur at the watermark.

This phenomenon may also occur on land. For example, let us consider a rod planted in land, the section near to the surface is in contact with more dioxygen (colourless, odourless and insipid, this gas is indispensable for many life forms, it participates in oxidation-reduction reactions and essentially in combustion and corrosion) than the deeper section, an electrochemical cell can therefore form between the deeper section and the surface section. Corrosion due to differential aeration.

8.5.1.4. Pitting

This is a corrosion phenomenon which occurs if a part is protected against generalised corrosion. This is local corrosion. This causes a small dot on the surface with a large cavity underneath.

On a long-term basis, this perforates the part and leads to increased embrittlement.

This is an undesirable type of corrosion as the external trace of corrosion is almost undetectable. This is in fact local galvanic corrosion.

8.5.1.5. Means of protection against aqueous corrosion

Wet oxidisable metals can be protected by insulation, using paint or a plastic film.

Cathodic protection also exists with a sacrificial anode, as well as impressed current cathodic protection.

A sacrificial anode is placed on the material to be protected with cathodic protection. In most cases, these anodes are zinc (easy to mould and good reactivity in aggressive environments). This is a means of controlling corrosion. Cathodic protection is used to protect metal structures, water pipes, pipelines, reservoirs, metal jetty columns, oil platforms and vessels and structures in reinforced concrete. In aqueous environments, you simply need to screw the sacrificial anode onto the part to be protected.

With larger installations, sacrificial anodes do not provide enough current for optimal protection. With an impressed current system, the anodes are connected to a DC generator. These anodes are in tube format or a compact rod of different materials.

8.5.2. Atmospheric corrosion

This corrosion is generated by the atmosphere and its conditions, at natural temperatures.

The particularity of this action is the change of conditions: depending on the weather conditions and the season, the material will be subject to different temperatures and different humidity levels.

The key parameter is the level of salinity. Salt may come from the sea, or the salting of roads in winter. However, pollution also has an important role to play, particularly for sulphur dioxide emissions, which cause acid rain and attack materials.

8.5.3. Stress corrosion

As the name indicates, stress corrosion is the result of the combined action of a mechanical stress and an aggressive environment for the material (either factor alone would not damage the material)

This is a dangerous type of corrosion for installations. Microscopic cracks will appear, which could be residual in origin (bending, cold lamination) thermal (expansion, pressure variations) or inherent to the function of the installation (suspension bridge cables, etc.)

Figure 65: Example of corroded screws and nuts

8.5.4. Means of combating corrosion

Several means of protecting against corrosion exist:

Corrosion inhibitors

These are a means of combating the corrosion of metals and alloys. Anti-corrosion treatment is not applied to the metal itself (coating, selection of a material resisting corrosion) but via the corrosive environment. The idea is not to modify the nature of this environment, but rather to add low quantities of the inhibiting formulation (isolated molecule, mixture of molecules) to the corrosive environment.

Surface treatments

This concerns chemical or electrochemical operations which modify the characteristics of the surface of materials and improve their resistance to corrosion. This operation is generally a preliminary stage in the application of paint.

If exposed to air, the part must be entirely coated. This is the principle behind galvanisation.

Organic coatings

The use of organic protective coatings is a method used to improve the durability of metal structures. The paint creates a layer of insulation between the surface of the metal and the aggressive environment: however the layer of paint will have defaults (scratches, holes, flakes) where corrosion may set in.

8.6. PROBLEMS RELATING TO FATIGUE

The resistance to fatigue of mechanical parts and their structures depends on many factors and on the material composing the parts and structures obviously. However, these parts will be more reliable if the designer has avoided concentration of stresses.

Almost 50% of all damage incurred by mechanical parts and structures during operation is due to fatigue ruptures. This is caused by the cyclic loading of critical zones with a concentration of stresses. In these zones, the gradual damage to the materials becomes evident in the form of micro-cracks, which will appear more or less rapidly depending on the type of material and the extent of the load applied.

Following the initial period, one or several of the cracks will spread through the thickness of the part until the latter suddenly breaks.

Many factors will have an influence on resistance to fatigue. The main factors are:

- The concentration of stresses: this is the key factor. (e.g. in a groove, the local stress exceeds the nominal stress >>> presence of a concentration of stress

- The condition of the surface: resistance to fatigue depends on this criterion (the worse the condition, the shorter the endurance due to the presence of superficial defaults)

- The scale effect: this means that, for an equivalent superficial stress, a larger part will have a shorter life cycle. With parts subject to bending, twisting or traction and showing notches, the development of the stress under the surface will influence the resistance to fatigue: the smaller the part, the greater its resistance to fatigue. The larger the part, the greater the probability of detecting a flaw which will lead to a fatigue crack.

- Residual stresses: these are caused in manufacturing. They occur in mechanical parts and will add to fatigue loads and modify mean stress.

- Corrosion, temperature, frequency: environmental factors. All of these factors will have an influence on resistance to fatigue. The endurance limit will be increased if the frequency of loading stress increases

It is therefore necessary to pay attention when selecting the bolts (type, material) to be used and their intended location (marine environment, underground) of use.

8.7. PROBLEMS RELATING TO AGEING

This is a considerable problem, especially for highly technical materials, which must be reliable even in extreme operating conditions.

The ageing process and the deterioration of the physical properties of a material are the result of processes affecting the composition and surface properties of the material, or even its crystalline structure, thereby altering its technical performances.

9. CONCLUSION

Bolts are subject to considerable stresses dues to maintenance including:

- successive tightening/loosening >>> extension, deformation
- deformed threads >>> increased clearance
- deterioration of surface condition >>> paint scratches, deterioration of part of the protective layer
- geographic location >>> marine environment, temperature variations, pressure variations.

For these and many other reasons, bolts are subject to constant stresses.

This is why maintenance must be particularly strict.

The following are essential:

- Careful compliance with manufacturer instructions.
- Always use the recommended bolts (do not change the diameter of the screw, this would change the assembly characteristics).
- Comply with the specifications for the material subject to maintenance (torque, screws and similar to be used for the different assembly operations).
- Use the right tools for the task to be carried out.

10. GLOSSARY

11. FIGURES

12. TABLES