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Why friction in screw connections is crucial for process capability

White Paper

Why friction in screw connections is crucial for process capability

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ASSEMBLY
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WHY FRICTION IN SCREW CONNECTIONS IS CRUCIAL FOR PROCESS CAPABILITY

Introduction

"Lean Production" is the current trend and represents even leaner and more target-oriented processes. Solutions for higher efficiency, lower consumption and longer service lives are being researched worldwide. When assessing new materials or processes for surface treatment or finishing, tribological properties such as friction, lubrication and wear are almost always a factor.

In industrial production, removable screw connections continue to be an important component while taking new designs and materials into account. With regard to material exploitation and process capability, ever-increasing requirements are demanded of the assembly processes.

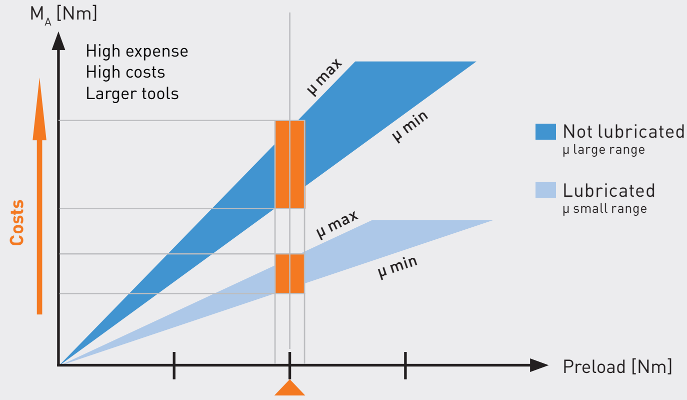


Illustration 1 Bossard, own illustration

Topics and insights for successful connection solutions

- Process capability
- Proccess reliability in assembly
- Tribology as a challenge

Challenge in screw technology

The market demands reliable end products with a high level of availability and longer maintenance cycles. In order to be able to fulfil these requirements, while taking the functional safety of the screw connections into account, suitable surface technologies are required. The material pairing and suitable corrosion protection must be sufficient for the external influences and stresses. They should, for instance, ensure the security of the connection even at higher operating temperatures such as at the attachment point for the exhaust duct on combustion motors.

However, in addition to the protective function, the technical surfaces must also fulfil the tribological requirements on the assembly line. Classically, screws are assembled with the existing friction influences between the surfaces moving relative to one another with which the effective screw preload is decisively influenced by the applied assembly torque.

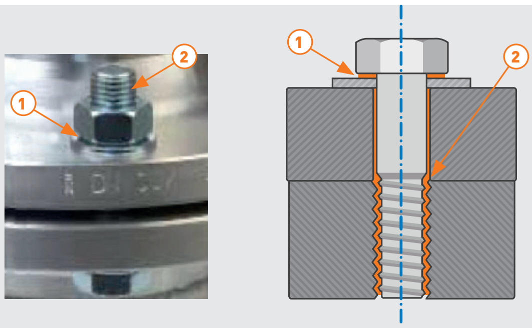
A process-capable screw assembly demands a constant and low friction dispersion (Illustration 1) on the threading and screw head contact surface. Lubricating the connection elements is, therefore, a basic requirement for the reliable quality of the connection.

As a result of the statutory constraints for environmentally and health-friendly use of industrial products, more focus is also being placed on the financial aspects. Fluid lubricants are being increasingly taken into account by means of lubricant additives in the functional dry coats on the screw connections (top coats) and applied on the base coats. A wide range of new surface protection systems with good corrosion protection properties have established themselves on the market which are similar or even superior to the chromate coatings containing Cr(VI) which they replace. The standardization of surface technologies is, however, limping behind industrial coating technology. The standardization for calibrated friction value and corrosion protection data is becoming more and more difficult due to the wide range of Cr(VI-free surface coatings combined with top coats.

Conclusion

The automotive industry is actually a technology driver with regard to the specifications for corrosion protection and the friction value ranges for reliable factory assembly processes and covering all of the requirements for safe operation. The companies in the international field are under growing pressure to find even better solutions that support more efficient assembly conditions and longer operating cycles.

The use of comprehensive solutions with a coating concept for specific performance characteristics is increasing. In particular, there are various base coats with top coats on offer (e.g. zinc flake coating systems). Anti-friction coatings with friction coefficient specifications are preferably applied by the same coater.



1 Lubricating the contact surface
2 Lubricating the threaded section

Illustration 2 Flange connections with high requirements for tightness and a surface pressure as uniform as possible due to the bolt pre-load.

WHY FRICTION IN SCREW CONNECTIONS IS CRUCIAL FOR PROCESS CAPABILITY

Process capability

For safety-related screw connections in which the right pre-load force must be ensured, manual assembly without a controlled tightening process is not suitable. Detecting all relevant influence variables for process reliability is necessary so, in particular, the consideration of the friction value dispersion and the successful selection of the right screw can be taken into account.

In accordance with a rational approach, a practical procedure can be derived from the automotive industry based on the risk analysis on the screwing process. VDI 2862 is a potential basis for the classification of screw connections and a guideline for the selection and use of corresponding screw systems. This guideline divides the screw connections into three risk classes in the automotive industry. Reliable assembly processes are thus connected to the right use of tools, etc.

Risk class A

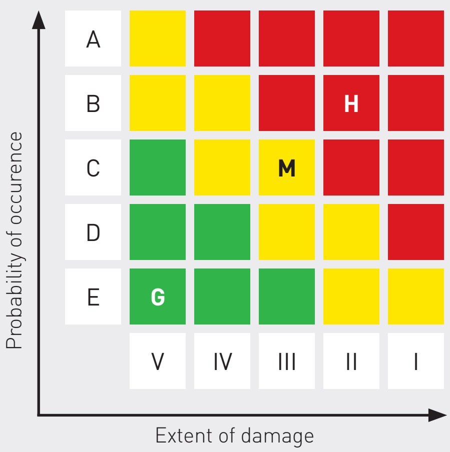
"Direct or indirect risk to life and limb" applies when the failure of this screw point may, with high probability, result in safety-related failures or the destruction of the machine/device/vehicle and thus pose a direct or indirect risk to life and limb.

Risk class B

"Functional stoppers" applies when the failure of the screw point leads to a functional fault in the vehicle.

Risk class C

"Customer annoyance" applies when the failure of the screw points leads to customer annoyance.



H = Urgently necessary measures

M = Improvements to be taken into account

G = Organization or staff-related measures

Illustration 3 Bossard, own illustration

Measurable process improvements with the help of key figures

The process capability indices C_p and C_{pK} are key indicators in the statistical evaluation of a process characteristic. You specify the compliance reliability with the target window in accordance with the specification. Thus, the friction value, the specified torque and the target pre-load on the component can be defined as a test characteristic.

The C_{pK} value is defined as follows, based on the average value **μ**, the corresponding standard deviation **σ** and the upper (OSG) or lower (USG) specification threshold:

$$C_{pK} = \frac{\min(\mu - USG; OSG - \mu)}{3\sigma}$$

The higher this value is, the more reliable the entire measurement series is within the specification.

The C_p value is defined as:

$$C_p = \frac{OSG - USG}{6\sigma}$$

The C_p value can only be calculated if both an upper and a lower specification threshold have been defined.

While the C_p value only indicates the ratio between the specified tolerance and the process dispersion, the C_{pK} value also includes the location of the average value with regard to the specified tolerance mean. In the best case scenario (process average is exactly in the middle of the tolerance range), $C_{pK} = C_p$; otherwise, $C_{pK} < C_p$.

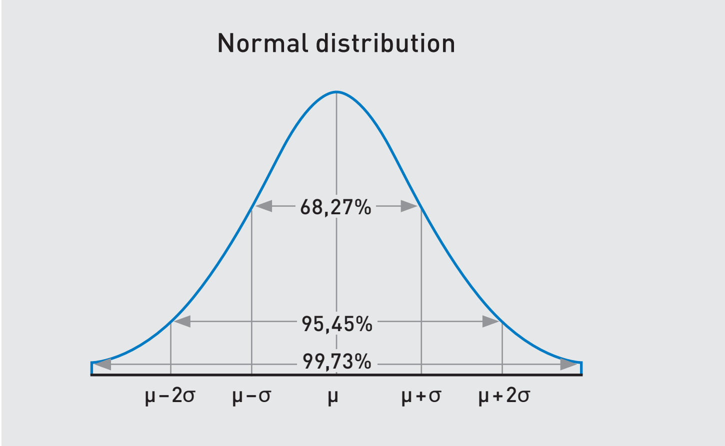


Illustration 4 Normal or Gauss distribution (according to Carl Friederich Gauss)

Conclusion

Assembly process capability is, accordingly, an important requirement for keeping assembly throughput times low. Friction deviations or even screw breaks often lead to unscheduled shut-downs in assembly operations. This must be prevented by the right framework conditions for screwing and the corresponding assembly specifications. A high level of process reliability therefore means, being able to properly implement the pre-load in accordance with the expectations.

WHY FRICTION IN SCREW CONNECTIONS IS CRUCIAL FOR PROCESS CAPABILITY

Process reliability in assembly

Reliability is determined largely by the assembly pre-load. Assembly is performed based on assembly specifications and the tribological boundary conditions. The assembly pre-load force is severely influenced during the assembly process by the friction on the threading pair and contact surfaces (connection element - component). The degree of effectiveness of the assembly when assembling screws is only at approx. 10 to 20%! (see also illustration 8)

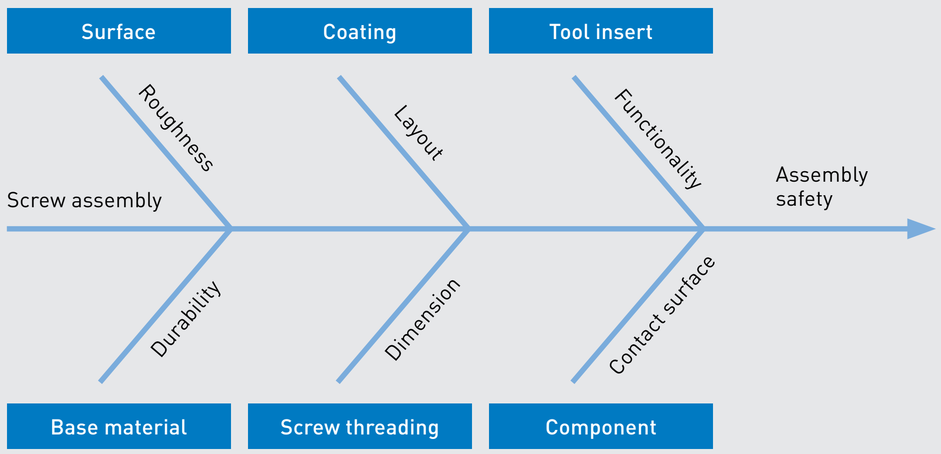


Illustration 5 Bossard, own illustration

Tribological boundary conditions in the screw connection

This makes it clear that the target pre-load in accordance with the design calculation can only be achieved with clearly defined tribological boundary conditions. Reliable assembly processes also requires minimal dispersion of the friction. For safety-related connections, practical application requires defined lubrication. Much along the lines of "lean production" for shorter throughput times and cost reduction, the flow of all activities from requirements reporting to the acceptance of the product, must be optimally organized. Activities in production, such as preparatory measures, do not actually create value and should therefore be avoided. Tribological dry coatings directly on the connection elements improve the required assembly reliability with defined friction value ranges for the target pre-load (Bossard coatings such asecosyn®-lubric).

Conclusion

Economical assembly is based on simple assembly processes using the right assembly tools. The screw elements with their tribological characteristics are crucial for achieving the required assembly pre-load.

Safety-related connections must therefore be equipped with new screw elements and, if necessary, documented with their label assignment (manufacturing batch).

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Tribology as a challenge

Even around 1880 B.C., the Egyptians were able to transport the alabaster Colossus by implementing measures for reducing friction. An actual lubrication concept with clear responsibilities for controlling the tribological conditions can be derived from the traditional records.

In accordance with DIN 51834-2, tribology is described as follows: "Tribology is the science and technology of surfaces affecting each other in relative motion". It covers the entire subject of friction and wear, including lubrication and includes corresponding boundary surface interactions between both solid bodies and solid bodies and fluids and gases.

Friction is an interaction between the contact surfaces of two bodies. It counteracts relative motion and is the loss of mechanical energy when processing, stopping motion or concluding a relative motion of two contacted surfaces. Friction can also be defined as an irreversible thermodynamic process.

A potential assignment of friction classes with reference values for different materials/surfaces and lubrication statuses for screw connections can be found in VDE 2230.

The published data usually only applies under laboratory conditions and room temperatures and must therefore be continuously reassessed for the respective application and specific usage conditions. The friction values, µtot, µth, µb indicate dispersions as they are dependent upon several factors, e.g. material pairings, surface quality (roughness), surface treatment (bare, galvanized, zinc flake coating, sealed, etc.) and the type of lubrication (with/without oil, molybdenum sulphide, graphite paste, PTFE lubricant, etc.).

Defined friction ratios are an important for both the head contact surface and the thread with regard to design and assembly reliability.

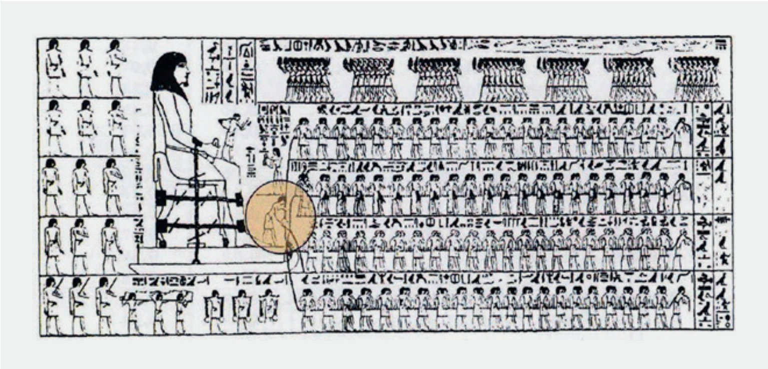


Illustration 6 Transporting an alabaster Colossus in Egypt

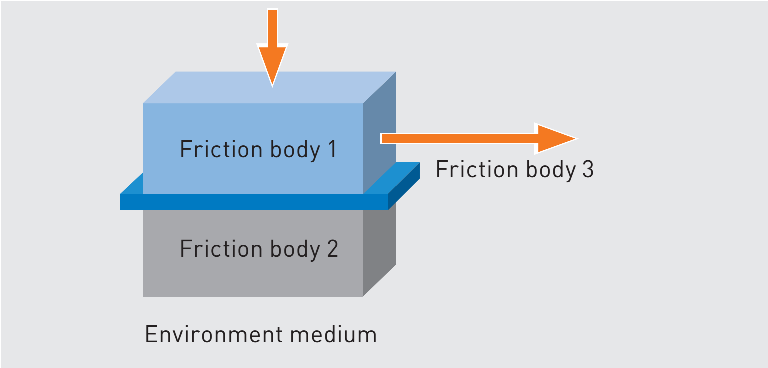
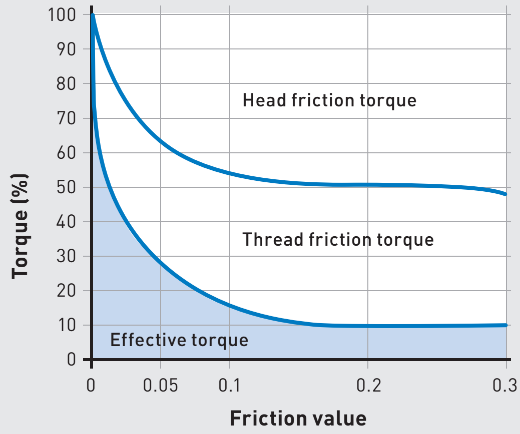


Illustration 7 Friction in the screw connection and separating joins and their influence varia-bles



$$M_A = F_M \left[\frac{d_2}{2} \tan (p + p_G) + \frac{D_{km}}{2} \tan p_K \right]$$

Illustration 8 The friction value μ, is largely dependent upon the: Material pairing, surface quality, surface treatment, lubrication.

Wear is defined as progressive material loss of the surface of a solid body, resulting from mechanical causes, i.e. contact and relative motion of a solid, liquid or gaseous counter-body. It is expressed by the occurrence of particles (wear particles) dissolving and material and form changes of the tribologically affected surfaces.

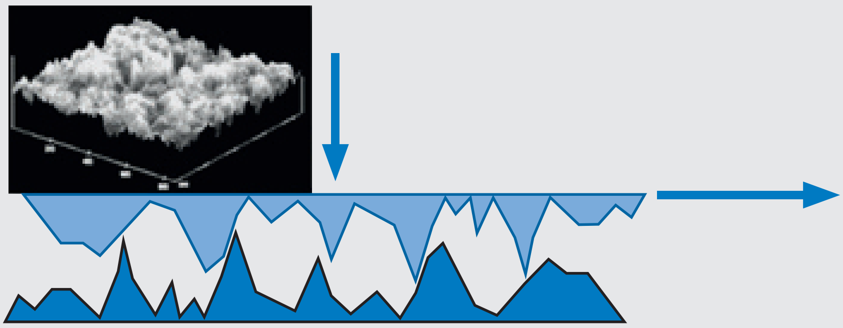


Illustration 9 Wear due to surface roughness

Lubrication

The total friction value μ_{tot} for a lubricant is crucial for determining the torque on a screw connection and the resulting assembly pre-load force.

Safety-related screw connections must be lubricated, in particular, bare, galvanized surface coatings or zinc flake coatings as well as rust-resistant screws. The potential operating temperature for the screw connections is generally between –50°C to max.+80°C. The conventional friction value ranges for reliable assembly processes are usually based on a friction value **μ_{tot} from 0.1** (dispersion range **μ_{tot} = 0.1–0.14**).

If another lubricant with a dispersion range greater than μ_{tot} = 0.1–0.14 is used, further clarification and adjustments are recommended or even necessary. The real friction values should be checked, if necessary, by means of corresponding tests.

The lubrication status "dry" requires special consideration and cannot cover the requirements of controlled tightening (friction values are undefined).

Instead of the fluid lubricants, tribological dry coatings, so-called "anti-friction coatings" are being used more and more, as they offer clearer benefits for more economical assembly.

- Defined lubrication ratios with higher assembly reliability in factory assembly and maintenance
- Lubrication must not be forgotten
- Economical assembly, disassembly without additional work preparation
- Reduction of the assembly costs due to an efficient working method

The tribological dry coatings are system solutions for mechanically stressed mounting elements (screws, nuts, washers). The coatings usually consist of non-electrolytically applied thin coats with integrated lubrication properties. The so-called top coats (e.g. anti-friction coatings) create a smooth film which evens out all of the irregularities on the surface and thus optimizes the friction conditions, even under extreme stresses and working conditions.

Effect of the lubrication displayed based on non-binding reference values for friction values with/without lubrication:

Threading friction value without lubrication

Srew material	Nut material	Range
bare – untreated	bare – untreated	0.18 – 0.35
bare – phosphate-coated	bare – untreated	0.25 – 0.40
zinc-galvanized	bare – untreated	0.11 – 0.36
bare – phosphate-coated	bare – phosphate-coated	0.13 – 0.24
zinc-galvanized	zinc-galvanized	0.18 – 0.42

Threading friction values lightly lubricated

Srew material	Nut material	Range
bare – untreated	bare – untreated	0.14 – 0.26
bare – phosphate-coated	bare – untreated	0.17 – 0.30
zinc-galvanized	bare – untreated	0.11 – 0.20
bare – phosphate-coated	bare – phosphate-coated	0.11 – 0.17
zinc-galvanized	zinc-galvanized	0.13 – 0.22

Threading friction values with specified tribological coating on the screw

Srew material	Nut material	Range
zinc-galvanized + tribo-coating in accordance with VDA235-104	zinc-galvanized	0.09 – 0.14
zinc-galvanized + tribo-coating Bossard anti-lubricfriction coatings	zinc-galvanized	0.09 – 0.12

Illustration 10 Effect of lubrication

Conclusion

Tribology can be described as a separate, interdisciplinary subject for optimizing mechanical technologies by reducing friction and wear-related energy and material losses. Since the surface coatings in use are subject to functional erosion, the colour, surface condition and, depending on the screw material used, the residual risk of failure is a reason to replace them. A planned observation and recurring inspection (assessment) for safety-related screw connections is recommended.

Objectives of tribological measures for optimizing mechanical systems	Frequency of the objectives being mentioned by users (100 % = 978 references)
1. Service life extension	
2. No-maintenence	
3. Load/RPM increase	
4. Production improvement	
5. Reduction of electr., loss capacity	
6. Leak reduction, sealing	
7. Noise reduction	
8. High temperature applications	
9. Vibration reduction	
10. Weight reduction	
11. Miscellaneous	

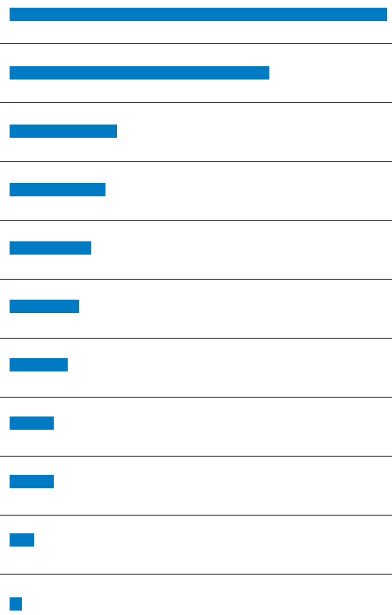


Illustration 11 Characteristic tasks in tribology

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