





Title page

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Synopsis

This report is the product of a bachelor project, made in cooperation with Arvid Nilsson, Kolding. The project is about friction analysis of bolts. The report are constructed over a series of friction test. These tests are performed with a combination of different fasteners and lubricants.

The test setup is described in detail, and some of the factors that influence the tightening of a bolted joint.

The friction coefficients for the different combinations are analyzed and the characteristics of the different type of bolts are described in the conclusion.

Jacob Mortensen

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Preface

This bachelor project is created in cooperation with Arvid Nilsson, Kolding over the time period 28/10/2013 - 6/1-2014. The purpose with the project is to show the skills and knowledge that is acquired through education and previous project, and to show the ability to acquire new knowledge.

In addition to the report are there attached a CD, with a digital version of the report and all the test results. There are in the end of the report and appendix section containing the results of the experiments, larger tables and calculations.

I would like to thank

Morten Frydendall

Anders Schmidt Kristensen

Janne Rantamäki

for their help with this project.

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1 Introduction

This report is produced in cooperation with the Application Technology department at Arvid Nilsson, Kolding. Arvid Nilsson is a sales company that provides fasteners for retail and industry. Their Application Technology department provides engineering services for the industry costumer, whether it is help with which material to use for specific environment, design of new solutions, test of fasteners or calculation of tightening torque. The majority of the questions the industrial customers have concerns the tightening torque needed to obtain the desired preload. This problem can be quite more comprehensive then it seems. There are a lot of factors that act on this calculation, and often more factors than there were initially expected.

The friction coefficient for the bolted joint has a high influence of the tightening torque needed. This is however not always a factor that can be predicted, if not the right precautions are taken. Furthermore can the friction coefficient vary from fastener to fastener, even though the same material and surface treatment are used.

This report will through comparison of theory and experiments process the tightening methods and how to achieve a precise and uniform tightening of a bolted joint. The main area of focus will be the friction of the fasteners and how to control this friction. With the well-defined and uniform friction coefficient will it be much easier to calculate the needed tightening torque. Furthermore will it be possible to reduce scatter, and thereby raise the utilization of the fastener, since the safety margin does not have to be as large. A better utilization of the fastener can in some cases lead to a lowered demands of the fasteners. This can result in reduced cost of the bolted joint, since the fasteners can be replaced with a fastener of lower strength or size.

2 Bolts in general

Bolts can generally be described by using standards. To obtain the best result will there in this project be used bolts, nuts and procedures in accordance with international standards, when possible. This chapter will describe the bolt design, material properties and the different types of surface treatments.

2.1 Design

Design of bolts and nuts are described in a large number of standards. The desired geometry of the nut or bolt decides what standard to use. The bolts, used to the experiments performed in connection to this report, are designed in accordance with ISO 4014, while the nuts are designed in accordance to ISO 4032. The basis of this choice is to test a connection that can be described as regular. This involves the use of a standard metrical thread (in accordance with ISO 68-1) and a contact surface, between the nut and the test set-up, with a size that represent a widely used number of bolted connections.

2.2 Material

Most of the fasteners sold by Arvid Nilsson are made of carbon steel or stainless steel. Based on this fact will there for the experiments be used fasteners of these materials. The following two chapters will describe the standards for carbon steel fasteners and stainless steel fasteners respectively. There will be a short description of the material, including their strengths, weaknesses and properties in general.

2.2.1 Carbon steel

The international standard (ISO) for material to carbon steel fasteners is the ISO 898:2012. This standard contains all the relevant information about the steel used for carbon steel fasteners, like designation, property classes, requirements to physical and mechanical properties and how to verify these properties. Carbon steel fasteners can be separated into different group in accordance to their strength. These groups, called property classes, are for bolts listed in Table 1 with the strength properties in MPa.

Property class	Tensile strength	Yield strength	Nut property class
4.6	400	240	4
4.8	400	320	4
5.6	500	300	5
5.8	500	400	5
6.8	600	480	6
8.8	800	640	7
9.8	900	720	8
10.9	1000	900	10
12.9/ <u>12.9</u>	1200	1080	12

Table 1. Shows the property classes and the requirements to the strength (in MPa) of the fastener with the respective property class.

The strength properties cannot be copied directly to the nuts, hence their strength are described with a proof load value. This proof value is then set to be higher than the tensile strength of a bolt with corresponding property class. Nuts with higher strength than the bolt results normally in the preferable fracture, where it is the bolt that fractures, and not the thread in the nut or on the bolt. The reason for this fracture to be considered an advantage in contrast to fracture in the thread, are the ability to discover a fracture. A

thread stripping fracture can be hard to detect since this kind of fracture not always is visible, resulting in an assembly that on the surface looks okay, but does not have the required clamp force in reality. There will for the experiments with carbon steel bolts and nuts be used bolts of property class 8.8, and nuts of property class 8.

Carbon steel will corrode as long as oxygen is present. This process is only possible to stop completely by placing the carbon steel fastener in an oxygen free environment. Since this is not a possibility in most cases are carbon steel fasteners normally corrosion protected by a surface treatment. Some of these specific treatments are described in 2.2.3 Corrosion protection. Surface treatment of a carbon steel fastener will not stop the corrosion, but only slow it down.

2.2.2 Stainless steel

Materials for stainless steel fasteners are described in ISO 3506:2009. This standard contain, like the ISO 898:2012 for carbon steel, all the relevant information regarding the steel used to produce fasteners of stainless steel. Designation of property class and steel type is constructed so the first part of the designation describes the type of steel with a letter (austenitic [A], Martensitic [C] or ferritic [F]) and a subgroup of chemical composition with a number. This part is used to determine the chemical properties of the steel, while the last part of the designation is the steel grade described by the strength of the fasteners with a number corresponding to 1/10 of the tensile strength in MPa. There will for the experiments be used stainless steel fasteners of the steel grade A4 and with property class 80 (A4-80). A4-80 stainless steel fasteners corresponds in strength to a carbon steel bolt with property class 8.8 and carbon steel nuts with property class 8. Furthermore do the stainless steel fasteners, as the name reveals, have a much better resistance to corrosion. This corrosion resistance is the result of a chromium content of at least 10,5 %, and normally over 16% for fastener material. The chromium content in the steel makes an oxide layer of chromium oxide on the surface of the fastener. This layers protects the fastener by blocking oxygen diffusion to the steel, and thereby stopping corrosion. The chromium oxide layer is in some way self-repairing. This means that if the stainless steel is subject to mechanical damage that destroys parts of the passive layer, the layer will automatically rebuild and make the material corrosion resistant again. The oxide layer can only rebuild if the content of oxygen in the air is sufficient.

2.2.3 Corrosion protection

Plain carbon steel fastener will instantly react with the oxygen in the air surrounding it, at start corroding. This process can be slowed down by treating the fasteners with different kinds of surface treatments. In the following chapters will the surface treatments chosen for the experiments be described. These surface treatments are also some of the most common surface treatments.

2.2.3.1 Electrically galvanization

Electrically galvanization of fasteners are described in ISO 4042. The standard describes the requirements to dimension, layer thickness, test of coating etc. Electrically galvanization treatment are performed though a process called electroplating. The fasteners are coated with a thin layer of zinc with the help of an electric current. This layer protects the steel fasteners, since the zinc act as a sacrificial anode. Electrically galvanized fasteners has a quite thin and smooth layer of zinc. This is not a sufficient treatment for fasteners that has to be used in corrosive environments. Here are the Hot-dip galvanized fasteners more suitable, since it has a much thicker layer of zinc.

2.2.3.2 Hot-dip galvanization

Hot-dip galvanization of fasteners are described in ISO 10684. This treatment adds a layer of zinc to the fastener like the electrically galvanization does. This layer is much thicker on the hot-dip galvanized fastener, as a result of the application process. The zinc layer is on the hot-dip galvanized fastener applied by lowering the fastener in a bath of melted zinc. This adds a layer of zinc on the fastener that gives protection against corrosion.

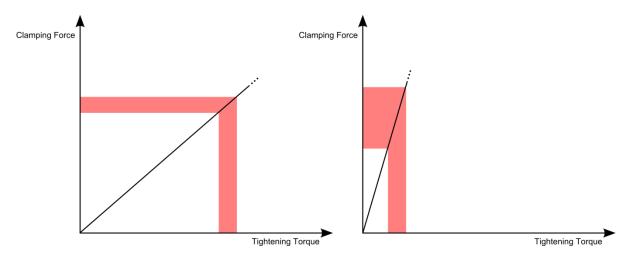
2.2.3.3 Zink flake

Zinc flake fasteners are described in ISO 10683. This treatment adds a layer of generally zinc and aluminum flakes to the fastener. The zinc flake layer is applied as a paint in a thin layer of approximately 8-12 μ m. This gives a high corrosion protection. Zinc flake is often applied in two layers, a base coat and a top coat. The base coat are for corrosion protection. Friction control can then be added by applying a top coat of wax or some of the solid lubrication agents as PTFE, MoS₂ and graphite.

2.2.4 Friction control

There are several ways of controlling the friction coefficients of fasteners, where some are more efficient than others. A uniform friction coefficient will make it more likely to obtain a uniform tightening, which is desired. Friction is the result of the mechanical resistance that occurs when two surfaces slides against each other. This leads to a loss of mechanical energy, in the way of heating of the affected elements, which are the surfaces, the lubricant and the surrounding air.

Friction is not necessarily a bad thing. A low friction coefficient will result in an assembly that has a tendency to lose clamping force, since the friction is too low to keep a locking effect. Furthermore will a low friction cause a more inaccurate tightening, since the scatter in torque provided by the tightening tools will have a larger impact on the clamping force. This is showed on Figure 1, where there to the left is a tightening diagram with a preferable friction and to the right a tightening diagram for an assembly with a low friction coefficient. The friction can be read on the diagrams as the gradient of the curve.





As the diagrams show will the same torque scatter result in a much larger clamping force range when the friction coefficient are low. This does not mean that a high friction coefficient is preferable. A high friction coefficient requires a high tightening torque to achieve the desired clamping force, which can lead to tor-

sional fracture. An evaluation is therefore required for every assembly, reassuring an assembly with the requested properties.

A good lubricant will provide a uniform friction coefficient. The producer of the lubricant will normally provide the friction coefficient and the normal distribution for a plain M12 assembly. This can be used to give an idea of how the lubricant will change the behavior of the tightening. The value supplied by the manufacturer can only be used to make an evaluation of the friction coefficient. The individual lubricant will not display the same properties when used with different types of fasteners. Because of this is it recommended to perform tests with the specific fastener and lubricant to determine the friction coefficients for the specific setup.

Another benefit of using friction control, is that most product used to control friction also will provide a protection against seizing. Tightening of a bolt/nut assembly can result in very high temperatures, due to the rising pressure between the bolt thread surface and the nut thread surface. The pressure itself can result in adhesion, which is a formation and separation of atomic bonds between surfaces. The result of this is a fast rising surface temperature that, in combination with the rising pressure, can lead to seizing of the fastener. This means that the surfaces cold weld and further tightening or loosening of the fastener will result in fracture. A good lubricant, with a sufficient high load carrying capacity will prevent the direct metal-metal contact, by creating a thin film of lubricant between the surfaces. The absence of this metal-metal contact and heat from the friction that derives from it, will make sizing of the fastener less likely.

There are several types of lubricating agents, the most common are oil, solid lubricating paste or wax. Many bolts and nuts are already from the manufacturer treated with a thin oil layer, this is both to protect the fastener from oxidation under transport and to lubricate the fastener. Oil is however not a sufficient lubricant to use with large size of fasteners or with high tension assemblies. The high temperatures and pressure that is the result of tightening of these fasteners will simply make the oil vaporize, leaving the fastener without lubrication.

Wax is normally used to treat whole batches at once, but can also be used on individual fasteners. When the wax is dried will the fastener feel like it is plain. A common additive in waxes, are a UV additive that will make the fastener light up under UV light. The feel of the wax treated fastener is one of the main reason to choose wax rather than oil or solid lubrication paste, hence this gives a more clean assembly that still has a friction control and protection against sizing.

For larger sizes and high tension assemblies are solid lubrication paste highly recommended. This type of lubricant consist of an oil mixed with one or more solid lubricant, like MoS₂, Teflon (PTFE) or graphite. The reason this type of lubricant is recommended to high tension and larger size fasteners are the content of solid lubricant. When the fastener is exposed to the conditions that makes the oil vaporize, will the solid lubricant remain, keeping the fastener protected against seizing and providing friction control.



Figure 2. Shows a bolt and nut that is lubricated with Molykote 1000.

Solid lubricating paste is normally applied in one of two ways. Either by spray or by brush. In regard of the application method is it important to cover the contact surfaces completely. This means the bearing surface on the nut and the bolt thread. To achieve a good and uniform lubrication is it necessary to be thorough when applying the lubricant, and make sure the paste is at the very bottom of the thread, and there is not any spots without lubricant (as shown on Figure 2). When using solid lubricating paste to lubricate bolt assemblies, should there be a rim of excess paste, since this gives protection from the environment and helps achieving a better covering of the bearing surface.

2.2.4.1 Molykote 1000



Figure 3. Can of Molykote 1000. The brush is used for application.

Molykote 1000 is a solid lubrication paste that is based on a mineral oil. Molykote 1000 gives a uniform relationship between tightening torque and the achieved clamping force, by controlling the friction of the fastener. Even after several re-tightenings will the friction coefficients be the same, making Molekyte 1000 a lubricant that can assure a consistent tightening even multiple times with the same fastener. The properties provided by the manufacturer are shown in Table 2. Application shall be performed in accordance with the procedure described in last section of 2.2.4 Friction control.

Table 2. Properties for Molykote 1000, provided by the manufacturer.

Color	Brown
Temperature range	-30°C to +650°C
Friction coefficient, μ head	0,08
Friction coefficient, μ thread	0,13

2.2.4.2 Molykote G-rapid plus



Figure 4. Can of Molykote G-rapid Plus. The brush is used for application.

Molykote G-rapid Plus is, like Molykote 1000, a solid lubrication paste that is based on a mineral oil. The biggest differences between Molykote 1000 and Molykote G-rapid Plus are the load carrying capacity and

the friction coefficients. Molykote G-rapid Plus have a higher load carrying capacity, meaning it can be used with larger and higher loaded fasteners, than Molykote 1000. The friction coefficient of Molykote G-rapid Plus is furthermore a bit lower than Molykote 1000. The properties provided by the manufacturer are shown in Table 3. Application shall be performed in accordance with the procedure described in last section of 2.2.4 Friction control.

Table 3. Properties for Molykote G-rapid Plus, provided by the manufacturer.

Color	Black
Temperature range	-35°C to +450°C
Friction coefficient, μ head	0,05
Friction coefficient, μ thread	0,10





Figure 5. Gleitmo 605 in a 1:5 water solution.

Gleitmo 605 is a colloidal suspension of Gleitmo White Solid Lubricant in water. The water is used to distribute the wax evenly over the surface of the fastener. Gleitmo 605 results in a clean and non-greasing surface with a controlled friction coefficient. Gleitmo is especially suitable for treating a large quantity of fasteners, since it can be applied by centrifuge coating procedure. Gleitmo 605 contains a UV-illumination additive for coating control by means of UV-light with a wavelength of 340 – 380 nm. Application of the product can be conducted with different methods. For larger quantities are the most common method a centrifugal coating procedure, where a large basket with the degreased fastener is dipped in the Gleitmo 605 solution. After the solution is dried are the fasteners coated and ready to be shipped. It is recommended to dry the fasteners by hot air to minimize the risk of corrosion. Coating of a small amount of fasteners can be done by simply dipping them in the Gleitmo 605 solution and letting the solution dry. The dilution ratio between Gleitmo 605 and water used to coat the fasteners depend on the coating method. As a rule do the dilution ratio vary from 1:3 for the centrifugal coating procedure to 1:7 for the dipping procedure. The properties provided by the manufacturer are shown in Table 4.

Table 4. Properties for Gleitmo 605, provided by the manufacturer.

Color	Colorless shiny
Temperature range	-40°C to +110°C
Friction coefficient, μ total	0,11

2.2.4.4 Geomet 321[®] + PLUS[®] VL (Zinc Flake)



Figure 6. Bolt and nut treated with Geomet[®] 321 + PLUS[®] VL.

Geomet 321 is a zinc flake coating in accordance with 2.2.3.3 Zink flake. Zink flake coating has a lubricating effect by itself, but to control the lubricating effect additionally are some zinc flake fastener applied with a top coat of a lubricating sealer. Geomet is a product line of zinc flake coating, where the majority of the coatings have a lubrication top coat. The zinc flake fasteners used for the experiments are treated with a Geomet 321 base coat and a PLUS VL top coat. The base coat gives the outstanding corrosion protection, while the top coat give an additional corrosion protection and provides friction control. There are different kinds of top coat, depending of the desired friction coefficient. Application of zinc flake is normally by hot dipping, like the process of hot dip galvanizing. The properties provided by the manufacturer are shown in

Table 5. Properties for Geomet 321 + PLUS VL, provided by the manufacturer.

Color	Metallic silver
Temperature range	N/A
Friction coefficient, μ total	0,11

3 Bolt connection

The bolted joint is a good way to assemble to parts, in a way the can easily be reassembled again. The main job for at bolted joint is to keep the clamped part together. To achieve this do the preload has to be of a size that it can withstand different forces working on the bolted joint, preferably without reaching the yield strength of the fastener. The following sections will describe different tightening technics, give an introduction to the forces acting on a bolted joint through force/displacement diagrams and show a method of calculation the needed tightening torque.

3.1 Tightening technique

There are several ways to tighten a bolted joint. Most of the methods are shown in table from VDI 2230 that is to find in Appendix 1. The table do also describe the precision of the methods. The 8 method listed in the table uses one or a combination of the following general tightening methods:

- Torque-controlled tightening
- Yield-controlled tightening
- Angle-controlled tightening

Furthermore are there three more general tightening methods that are not mentioned in VDI 2230:

- Bolt stretch method
- Heat tightening
- Use of tension indicating methods

These methods are not mentioned in the VDI 2230, since calculation of tightening torque and preload, are very different for these method.

Torque-controlled tightening are the most widespread method, due to its cost-effective tools and easy handling. This method uses tools that measures the torque transferred to the fastener, and then either gives a signal or turns of when the desired torque is reached.

Angle-controlled tightening uses the theoretically relationship between the linear deformation of the bolt over the pitch of the thread and the angle of rotation the bolt are tightened. This is done be tightening the bolted joint enough to ensure full contact between the surfaces, and then rotate the bolt a calculated amount of degrees to obtain the desired preload. The two methods (torque-controlled tightening and angle-controlled tightening) can be combined, so the procedure is to tighten the fastener to eg. 75% of the preload, and then use angle-controlled tightening to tighten to fastener to the desired preload. The combination of the methods eliminate some of the cons the individual method has.

Yield-controlled tightening uses a tool, which tightens the fastener until the fastener reaches the yields point. This point is recognized by measuring the torque and the angle of rotation under the tightening process. When the yield point is reached will the relationship between these two factors change drastically, thereby revealing the yield point. This method eliminates the scatter from the variance in friction, but the preload is with this method a result of the size and material of the fastener.

The precision of the different tightening methods vary widely, as the table in Appendix 1 shows. This means that it is of high importance to choose the right tightening method for the job. Figure 7 shows a bolted joint

with a minimum preload of 30 kN, where to scatter for four different tightening methods are displayed as the orange area. Tightening with impact wrench (A) has a large scatter. It is therefore necessary to use a higher torque to ensure that the preload are at least 30kN. The size of the 12.9 bolt needed to avoid fracture, are shown under the charts. This shows that the right method of tightening can lead to large reduction in the needed bolt diameter.

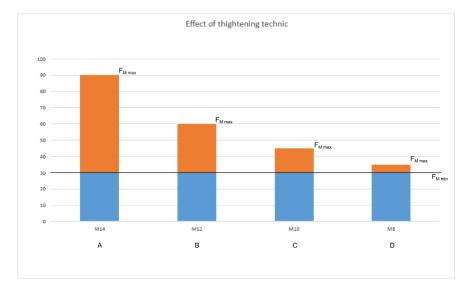


Figure 7. Shows the scatter of preload, when using different tightening method, and the size of 12.9 bolt needed to avoid fracture. A - Impact wrench, B - Bolt installation spindle, C - Torque wrench or precision bolt installation spindle, D - Yield-controlled installation spindle.

3.2 Force/displacement description of bolts

A force/displacement diagram is a good way to visualize the all the forces working on a bolted joint. A bolted joint are showed in three different states in Figure 8. Figure 8-1 shows the initial state of the preloaded assembly where the preload F_m is not produced yet. Figure 8.2 shows the assembled state after the preload is introduced. The last state shown in Figure 8.3 are the working state. Here are the bolted joint affected by both the preload and a working load. In between the initial state and the assembled state are the bolted joint tightened to introduce the preload F_m . The preload force are pushing the clamped parts together, resulting in a clamp force F_K at the interface. In the working state are the bolted joint introduced to an axial working load F_A that is acting on the clamped parts.

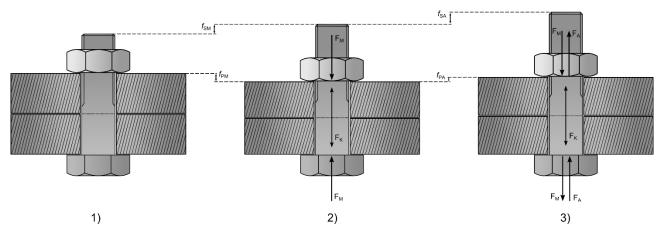


Figure 8. Preloaded bolted joint. 1. Initial state. 2. Assembled state. 3. Working state.

The forces acting on the bolted joint leads to chance in size of the clamped parts and the bolt. The preload and the therefrom produced clamp force results in a compression f_{PM} of the clamped parts, and an elongation f_{SM} of the bolt. In the assembly state are the clamp force identical to the preload, giving:

$$F_M - F_K = 0 \tag{3-1}$$

If the bolted joint is exposed to a working load, will this lead to an increase of the force acting on the bolt F_{SA} , resulting in an elongation of this f_{SA} . This elongation will relieve the clamped parts with a corresponding force F_{PA} elongating the clamped parts with the same length f_{PA} . The clamp force is therefore reduced by the workload, while the preload is the same as in the assembled state. This gives us:

$$F_M - F_K - F_A = 0 (3-2)$$

These states can be visualized be using a force/displacement diagram. This is a diagram as shown on Figure 9-2. The figure shows the assembled state of a bolted joint, which is the state displayed on Figure 9-1. The diagram has gathered the graph for the bolt and the plate in the same diagram to make it possible to compare them. This is done by mirroring and displace the graph for the plate parts, since these parts are subject to compression instead of the elongation the bolt are subject to. The graphs shows that the elongation and compression of the bolt and plate parts respectively, are linear in regard to the force the parts are exposed to. It is furthermore possible to see that the bolted joint meets equation (3-1), since the preload and the clamp force are of the same size.

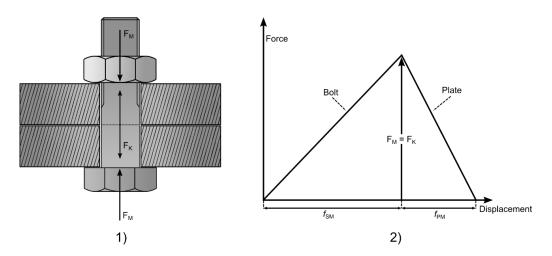


Figure 9. Shows the assembled state of a bolted joint (1), and the corresponding force/displacement diagram (2).

The force/displacement diagram for the working state are shown on Figure 10. When the working load is introduced will the load on the bolt part be increased, which shows in the diagram as the elongation of the bolt graph. The diagram displays how the working load affects the clamp force and how the forces acting on the bolt and plate part are changed. The diagram also visualizes how the change in length of the bolt part and the plate part are identical, even though the load added to the bolt and relieved from the plate parts can be quite dissimilar.

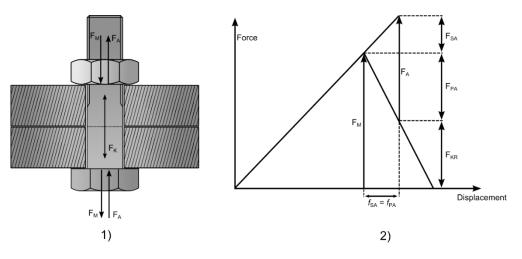




Figure 11 shows a state where the work load is greater than the preload, resulting in a reduction of the clamp force to zero. This means that the plate parts will separate and a gab will occur between them. This is naturally not a desired, since the gab can result in failure.

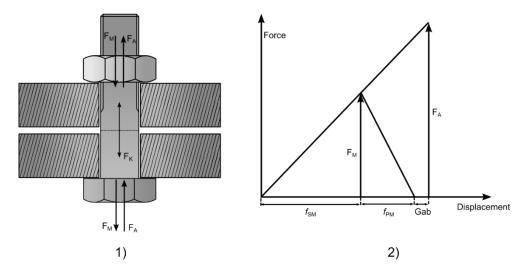


Figure 11. Shows the gap state of a bolted joint (1), and the corresponding force/displacement diagram (2).

3.3 Calculation of tightening torque

Torque-controlled tightening is the most common way to tighten a bolted joint. To obtain the necessary preload, do the corresponding tightening torque have to be calculated. The total tightening torque M_A , that is required to obtain the desired preload F_M , consists of the thread torque M_G and the head or nut torque M_k .

$$M_A = M_G + M_K \tag{3-3}$$

If there for the bolted joint are used fasteners that prevent loosening (self-locking nuts, serrated bearing face bolt, etc.), are the overbolting moment $M_{\ddot{u}}$ and the additional head moment M_{KZu} added to the total tightening torque.

The equation for the thread torque can be derived by looking at the relations between the clamping force and the thread torques point of attack and direction. The thread torque are working at the pitch diameter d_2 , with the helix angle of the thread φ in the perpendicular direction to the axis and the angle of friction ρ' as a tangent to the axis.

$$M_G = F_M \cdot \frac{d_2}{2} \tan(\varphi + \rho') \tag{3-4}$$

For metric thread are the pitch P and the flank angle α used:

$$\tan(\varphi) = \frac{P}{(\pi \cdot d_2)} \tag{3-5}$$

$$\tan(\rho') = \mu'_G = \frac{\mu_G}{\cos(\frac{\alpha}{2})}$$
(3-6)

Both metric and unified fasteners has a flank angle α =60°, giving μ'_{G} =1,155 μ_{G} . This can be used to simplifie the equation.

$$\tan(\varphi + \rho') \approx \tan(\varphi) + \tan(\rho')$$

$$= \frac{P}{(\pi \cdot d_2)} + 1,155\mu_G$$
(3-7)

Thus:

$$M_G = F_M(0,16 \cdot P + 0,58 \cdot d_2 \cdot \mu_G) \tag{3-8}$$

To derive the equation for the head/nut friction moment do the radius to the friction diameter need to be known. This radius can be calculated by:

$$D_{Km} = \frac{d_w + D_{Ki}}{2}$$
(3-9)

Where

$$D_{Ki} = \max(D_a, d_{ha}, d_h, d_a) \tag{3-10}$$

The variable d_w are the outside diameter of the bearing surface at the head or at the nut. Furthermore are inside diameter of the bearing surface at the head or at the nut defined by which diameter is the largest of the chamfer diameter of the nut D_a, the chamfer diameter of the clamped parts d_{ha} , the hole diameter d_h or the inside diameter of the plane bearing head area d_a . The moment required to overcome the friction between the bearing surface and the head or nut, can then be calculated from the following equation:

$$M_K = F_M \cdot \frac{D_{Km}}{2} \cdot \mu_K \tag{3-11}$$

By combining the thread torque M_G (3-8) and the head or nut friction moment M_K (3-11), so they follows the principle of equation (3-3), gives the equation for tightening torque. Here are the variables the desired clamp force, the friction of the thread and the friction bearing surface between clamped parts and head or nut.

$$M_A = F_M(0,16 \cdot P + 0,58 \cdot d_2 \cdot \mu_{G+} \frac{D_{Km}}{2} \cdot \mu_K)$$
(3-12)

A table of the sizes used the metric threaded fasteners are to find in Appendix 3, while the table for an approximated friction coefficient are to find in Appendix 2.

4 Experiments

This chapter will describe the test setup, how the test where performed, the factors of influence on the test and how these factors were controlled.

4.1 Test setup

The experiments where performed in accordance with ISO 16047, on the test machine shown on Figure 12. ISO 16047-"Fasteners – Torque/clamp force testing" are the international standard that specifies the conditions for carrying out torque/clamp force testing. The test machine are built, so it meet the requirements stated in ISO 16047. The test machine can be used to both torque/clamp force testing and a regular tensile strength testing.



Figure 12. The full test setup. 1. In test state with the safety glass and doors closed. 2. Close-up of the whole setup.

Figure 12-2 is a close-up of the whole setup, where it is possible to see how all the different parts are connected, that later in this section will be described individually. From the top and down does it consist of an electrical motor with gearing, a torque meter, test bench, another torque meter and three load cells.



Figure 13. Bauer BG50 4kW helical geared motor.1. seen from the front. 2. Seen from the side.

Figure 13 shown the electrical motor that tightens the fastener. There are for this test machine used a 4kW Bauer BG50 helical geared motor, which with its output and gearing are powerful enough to be used to be used with M24 and smaller. This motor can provide a stable RPM that is important for the experiments to meet the requirements of ISO 16047.

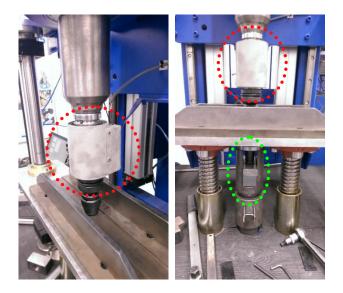


Figure 14. The torque meter are marked with a red circle. A tool to turn the nut is mounted on the torque meter, while the green circle marks the tool to hold the head of the bolt.

There are on the electrical motor mounted a torque meter, which are the white box marked with a red circle. The Torque meter can measure the torque the electrical motor supplies the bolted joint. Furthermore can the torque meter measure the RPM the fastener are tightened with. A tool to turn the nut is mounted on the torque meter, and the counterpart for the head of the bolt are mounted underneath the test bench.



Figure 15. Underneath the table. The shaft in the middle has a torque meter mounted, which is the lighter grey part. The orange parts on the side are motors/gears for changing the height of the test bench.

Underneath the table are the second torque meter mounted in the shaft, as seen on Figure 15. This torque meter is used to measure the thread torque, hence this is the only torque in the shaft. The picture also shows the electrical motor and worm gear for changing the height of the test bench. The same motor and worm gear are used to apply force, when the machine is used to tensile strength test.



Figure 16. Bottom of the test machine. In the middel are the shaft from the test bench. The three metal cylinders that is placed on the left, right and behind the shaft are the load cells.

At the very bottom are the shaft mounted on a plate, where three load cells also are mounted, as shown on Figure 16. The combined load on these three load cells represents the preload of the fastener.

The machine was last calibrated on 26/9-2013, less than two month before the experiments where performed. The calibrating made sure that the machine meet the requirements described in ISO 16047. Requirements like:

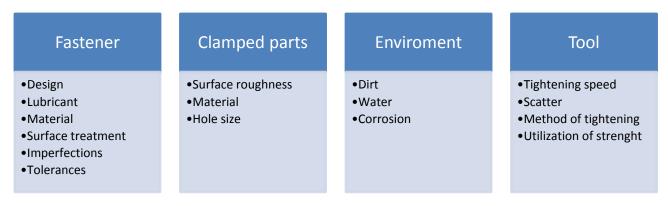
- Maximum ±2% deviation on the torque measurement
- Maximum ±2% deviation on the load cell measurement
- Maximum ±2% deviation on the angle measurement
- Tightening shall be carried out with constant speed

Additionally is it important that the stiffness of the testing machine, load cells and test fixture are constant throughout the test. The test machine used for the experiments meets all these requirements, except the stiffness of the testing machine that can be under dimensioned when testing fasteners that are larger then M20 10.9 and M24 8.8.

4.2 Factors of influence

The following shows some of the factors that influence the tightening of a bolted joint. This section will describe these factors and how they have been controlled in the experiments, if possible.





4.2.1 Fastener

The design of the fastener has naturally a large influence, since this is the determining factor for the placement and size of the contact areas. This factor is however not important in the experiments, since the fasteners used, all are with the same design and size.

Material, surface treatment and lubrication are all factors that the experiments covers. These are the factors that varies in the different experiments, in an effort to determine their influence.

Imperfections of the fasteners like burrs, slags and mechanical wear can often lead to seizing, since these imperfections can lead to very high pressure/temperature in a small area. To avoid this are the fasteners visual inspected, and tested with a go/ no go test of the thread before use, as seen on Figure 17.





Tolerances of the fastener have an insignificant influence on the tightening. As the calculations in Appendix 4 shows, are the difference in tightening torque for a M12x1,75 6G with maximum and minimum sizes only 0,5 %.¹

¹ <u>http://www.fullermetric.com/technical/information/tech_thread_tolerance.aspx</u> (last opened 5/1-14)

4.2.2 Clamped parts

The material and surface roughness influence the tightening of the bolted joint by the friction and the tendency to seize. In the experiments are there used a washer of to minimize the influence of these factors. There are used HV 200 steel washers for all fasteners of steel and HV 200 austenitic steel washer for the austenitic steel fasteners. Every experiment where performed with at new washer, to secure even conditions.

The hole size of the clamped parts does not affect the tightening in the experiments since the washer has a smaller hole diameter than the clamped parts.

4.2.3 Environment

Dirt, water and corrosion are all factors that is relatively easy to remove in the test setup, but can be hard to avoid in practice. These factors has the biggest influence on fasteners of smaller size. This is due to the surface pressure that is produced in fasteners of larger size. Water will quickly vaporize when the pressure builds, but can still be harmful since it can remove lubricant in some area, leaving the fastener unprotected. Dirt like sand can have a large influence on small size fasteners, but not with larger sizes of fasteners and a proper lubricant. The sand will be crushed by the large pressure, leaving the lubricants bearing surface between the bolt and nut.

4.2.4 Tool

As described earlier in the report do the method of tightening and the accompanying scatter have a great influence on the utilization of the fastener. This is however not a concern in the perform experiments, since the scatter of the tool used, maximum is $\pm 2\%$.

The speed of the tightening do however have quite an influence on the tightening. All the experiments will be performed with a tightening speed of 10RPM, which is the minimum recommend speed in ISO 16047 for at M12 fastener. Higher tightening speed raises the tendency for the fasteners to seize, especially for the austenitic steel that already has a high tendency to seize.

4.3 Test procedure

All the test where performed with the same procedure, which featured the following steps:

- Test bench is placed so the length between upper and lower parts fit the length of the bolt used. The distance should be so the bolt are the nut height + 1-2 thread over the upper part of the test bench.
- 2. All relevant data are entered in the computer.
- 3. Apply lubrication to the bolt and nut (if lubrication are tested). Or degrease the bolt and nut if a clean surface is desired.
- 4. The bolt is mounted in the tool and placed in the test bench.
- 5. Place the nut on the bolt and tighten by hand.
- 6. Lower the electrical motor.
- 7. Start test on computer.
- 8. Tighten nut until the desired preload are reached.
- 9. Untighten the nut, raise the electrical motor and remove the nut and bolt from the test bench.
- 10. Clean the test bench if necessary.
- 11. Repeat 3-10 if more fasteners are tested in same series.

All test without lubricant are performed first to minimize lubricant on the test bench. A change in lubricant includes are cleaning and degreasing of the test bench.

5 Results

This section will gather and compare all the measurements from the experiments. All the data from the experiments are located in Appendix 5. The test report results are split on two sides. The first side contains firstly the data entered in the test software on the computer, as shown on Figure 18. This is both to have the values to make the calculations, but also to note which conditions the test with executed with. Under misc. test data are the used lubricant and the proof load noted. The proof load are the load the nut shall withstand, without deformation or fraction. This is used in the tests, in that way that the tightening is stopped when the preload gets higher than the proof load.

Test data								
Test type: Separate Head and Thread friction								
Measure RPM 10								
Misc. test dat	ta (Lubrica	ation, washe	er type etc)					
Lubricated	with Moly							
Proof load:	48,9KN							
- Bolt data								
Dimension	M12	Length	-					
Strength	8]						
Surf.Treat.	Plain, o	iled						
Head WAF: 18mm								
Pitch(P)	1,75	00	17,25					
d2	10,863	dh	13,2					
Miss holt da	ta							

Figure 18. Part of a test report. The value entered in the test software to define the test parameters.

Secondly are the on the first side of the test report a table with all the results from the test series. The table contains the maximum preload reached, the corresponding tightening torque and the friction coefficient for the test. The friction coefficients are listed in total friction coefficient, head friction coefficient (μ_1) and thread friction coefficient (μ_2). There are underneath the table with the test data a statistics evaluation of the test series, with the average total friction coefficient and the standard deviation thereof.

- Test re	sults					- Statistics
	Fmax [kN]	Tmax (Nm)	µ total	μ1	μ2	Average µ 0,15
1	52,5	110,5	0,14	0,15	0,13	
2	49,5	111,7	0,14	0,16	0,12	Standard deviation u 0.01
3	48,7	108,9	0,14	0,16	0,13	Standard deviation µ
4	51,2	122,2	0,16	0,19	0,14	
5	50,8	117,6	0,15	0,18	0,11	
6	53,4	118,6	0,14	0,17	0,11	

Figure 19. To the left are the table with the test results and to the right are statistic evaluation of the test series.

On the second side are three diagrams. The first diagram are a revolution/torque diagram, as shown on Figure 20. This diagram are not very interesting for the experiments performed in this report.

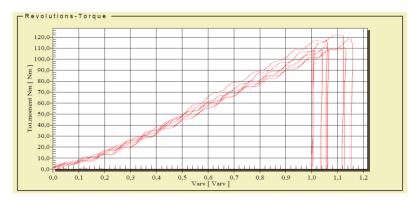


Figure 20. Revolution/torque diagram from the test report.

The second diagram is a torque/preload diagram as shown on Figure 21. This diagram is interesting because it visualizes the scatter of the test series. With a perfect test series, would all the line be on top of each other. This would mean that all the fasteners are performing identical. Scatter is easily observed on this diagram, hence the individual graphs then are spread apart. The gradient of the graph represents the total friction of the bolted joint.

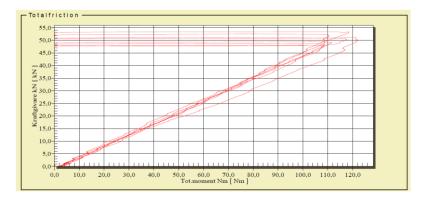
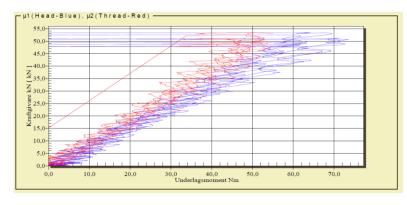


Figure 21. Torque/ preload diagram from the test report.

The last diagram are also a torque / preload diagram, but this has two graphs. The blue graph are for head torque, while the red one are for thread torque.





5.1 Friction coefficients

5.1.1 Plain Fasteners

Table 7 shows a table with all the results for the test series with plain fasteners, while the full test reports are to be found in Appendix 5, section A5.1- A5.4. Plain fasteners are normally delivered slightly oiled, mainly to prevent corrosion. But this oil do also have a lubricating effect, as the table clearly shows. When the fasteners are degrease increases the total friction and the scatter make the tightening process unpredictable. Even worse are the fact that the ungreased fastener cold-welded and fractured, before the preload value was achieved. Several other cold-welded in the end of the tightening, making it impossible to dismount the assembly without fracture. The oiled removed the tendency to seizing and showed a quite small scatter. G-rapid + as a lubricant give very good result, with a stabile total friction of 0,10 and an insignificant scatter. The Molykote 1000 did also show very little scatter, but had a unexpected high total friction coefficient, compared to the 0,08 and 0,13 that the manufacturer supplied.

The small scatter that the oiled fastener showed, might be the result of a relatively small size of fastener. Oil is a good lubricant, but with larger sizes, and thereby larger surface pressure, will the oil vaporize leaving the fastener without lubrication. This is not the case with the lubricant pastes, since they contains a solid lubricant that protects the fastener even though the oil is vaporized.

Fastener type and lubrication	Total friction coefficient	Standard deviation	VDI 2230, guidance friction coefficient
Plain, without lubricant	0,16	0,02	N/A
Plain, oiled	0,14	0,01	0,14-0,24
Plain, G-Rapid +	0,10	0,01	0,08-0,16
Plain, Molykote 1000	0,15	0,01	0,08-0,16

Table 7. The test series with plain fasteners.

5.1.2 Electrically galvanized fasteners (FZB)

The results of the test series with the electrically galvanized fasteners are listed in Table 8 and the full test results are in Appendix 5, section A5.4 – A5-8. This type of fastener are in delivery state without any oil. This is mainly due to the common use of this type of fastener. Electrically galvanized fasteners are rarely used in bolted joints with a high preload. As the test results show are the fasteners also pretty hard to use in the non-lubricated state. The total friction is high, and the scatter is very high, making it impossible to control the tightening. The torque/preload diagram shows the large spread of friction coefficient, and that the majority of the fasteners fracture before they reach the proof load. This is also the reason that it is common to treat electrically galvanized fastener with a wax, if the preload has some kind of significance. The Gleitmo 605 treatment shows a good total friction coefficient on 0,12, and a quite small scatter. The solid lubricants are both very convincing in their use, with a friction coefficient as advertised and an almost non-existent scatter.

Fastener type and lubrication	Total friction coefficient	Standard deviation	VDI 2230, guidance friction coefficient
FZB, without lubricant	0,25	0,04	0,20-0,35
FZB, G-Rapid +	0,09	0,00	0,08-0,16
FZB, Molykote 1000	0,10	0,01	0,08-0,16
FZB, Gleitmo 605	0,12	0,01	0,08-0,16

Table 8. The test series with electrically galvanized fasteners.

5.1.3 Hot-dip galvanized fasteners (FZV)

Table 9 shows a table with all the results for the test series with hot-dip galvanized fasteners, while the full test reports are to be found in Appendix 5, section A5.9- A5.12. The hop-dip galvanized bolt are in delivery state without oil, while the nuts are delivered slightly oil. Unlike the plain fasteners are the oil mainly for lubrication on hot-dip galvanized fasteners. Also in these tests are lubrication needed. The degreased fasteners have a hard time reaching the proof load and several fracture. Never the less do the degreased fastener act a lot better, than VDI 2230 had predicted. The oil treatment of the nut are like the plain fasteners enough to achieve a low friction coefficient and a surprisingly small scatter. The solid lubricant pastes do also with hot-dip galvanized fasteners show a good and uniform tightening.

Table 9. The test series with hot-dip galvanized fasteners.

Fastener type and lubrication	Total friction coefficient	Standard deviation	VDI 2230, guidance friction coefficient
FZV, without lubricant	0,16	0,03	0,20-0,35
FZV, oiled	0,12	0,01	N/A
FZV, G-Rapid +	0,11	0,01	0,08-0,16
FZV, Molykote 1000	0,12	0,01	0,08-0,16

5.1.4 Austenitic stainless steel fasteners

The test series with austenitic stainless steel fasteners are shown in Table 10, and the full test reports are attached in Appendix 5, section A5.13- A5.16. When performing the experiments with the austenitic steel fasteners, are it obvious that they act a lot different than the steel fasteners. The friction coefficients are much higher, and the tendency to seizing are very large. None of the non-lubricated fasteners that were tested reached the proof load. The test results in Appendix 5, A5.15 clearly shows why. There friction coefficient are so high, that the torque needed to build the desired preload are over 300Nm. This results in a torsional fracture of the bolts. The Gleitmo 605 treated bolts all made the proof load, but the scatter is high and the tightening very unpredictable. Some of the Gleitmo 605 treated fasteners did also get a plastically deformation of the thread, making them hard to disassembly and unusable after removal. Even the solid lubricant pastes are having a hard time holding the scatter at an acceptable level. Molykote 1000 do also have a quite high friction coefficient with austenitic stainless steel.

Fastener type and lubrication	Total friction coefficient	Standard deviation	VDI 2230, guidance friction coefficient
Austenitic steel, without lubricant	0,42	0,08	>0,30
Austenitic steel, G-Rapid +	0,11	0,02	0,08-0,16
Austenitic steel, Molykote 1000	0,17	0,02	0,08-0,16
Austenitic steel, Gleitmo 605	0,38	0,02	0,14-0,24

Table 10. The test series with austenitic stainless steel fasteners.

5.1.5 Zinc flake fasteners

The result of the Zinc flake fastener test series are shown in Table 11 and the full test results are to be found in Appendix 5, section A5.17- A5.19. The Zinc flake fasteners are not oiled, but the fasteners used for these test have a lubrication top coating. This results in very good and uniform tightening performance. The friction coefficient are stable does not change even when using the solid lubricant pastes. The scatter are extremely low with the fasteners that only are treated with the top coat. Applying extra lubricant in the form of G-Rapid + or Molykote, only increases the scatter. The increase is however very small, and the scatter is in a range, where the tightening is easy to control. For these experiments had it been more interesting to use Zinc flake fasteners without the lubricating top coat.

Table 11. The test series with zinc flake fasteners.

Fastener type and lubrication	Total friction coefficient	Standard deviation	VDI 2230, guidance friction coefficient
Zinc Flake, without lubricant	0,10	0,00	N/A
Zinc Flake, G-Rapid +	0,09	0,01	N/A
Zinc Flake, Molykote 1000	0,10	0,01	N/A

5.2 Tensile strength test

To ensure that the fasteners used for the experiment met the requirements in strength, were one of each type of fastener tensile strength tested. The full test report are attached in Appendix 6. The proof load value for a M12 property class 8 nut are listed to be 74,2kN in ISO 898-2:2012, Table 4. The results of the tensile strength test are listed in Table 12.

Table 12. Tensile strength test of the fasteners used for the experiments.

Fastener type	Tensile strength test
Plain	78,8kN
Electrically galvanized	78,6kN
Hot-dip galvanized	74,2kN
Austenitic steel	82,5kN
Zinc flake	75,8kN

The tensile strength test of the fastener shows that all the tested fasteners meet the tensile strength requirements.

6 Conclusion

The main conclusion to the test series, are that if bolted joint shall be tightened under controlled conditions, are some kind of lubricant a necessity. For the M12 size fastener, that have been used to the experiments in this report, are oil generally sufficient to achieve a uniform tightening and an acceptable level of scatter. Oil is however known to be insufficient when the surface pressure get higher, than it did in the experiments conducted in connection with this report.

Molykote 1000 is a widely used lubricant for fasteners. The tests has shown that Molykote 1000 performs very well for a many different types of surface treatments and materials. The scatter were significantly reduced by introducing Molykote 1000. The friction coefficient do however vary when using Molykote 1000 on different surface treatment and material. This is not a problem since the variation are small, and the scatter are of the range it is.

If a small variation is desired in the friction coefficient between different materials and surface treatments, are the G-Rapid + solid lubricant paste an option. This paste has shown very good results with every type of surface it has been tested on in this test. Even the austenitic stainless steel, where Molykote 1000 had a slight increase of friction coefficient, were no problem for the G-Rapid +. G-Rapid + had overall a friction coefficient of 0,10 and a highly controllable scatter.

Gleitmo 605 where tested on austenitic steel- and electrically galvanized steel fastener, which are the common types of fasteners to combine with this friction controlling treatment. This treatment showed good result with the electrically galvanized fastener, but were doubtful for use with the austenitic stainless steel fastener.

Using plain fasteners for a bolted joint, does not set strict requirements for lubricants in the sizes that have been used in this project. The plain fasteners have a quite predictable tightening, as long as they are lubricated. Even non-lubricated plain fasteners can be tightened without major problems. They do however not have the same predictability that the lubricated version has.

Electrically galvanized fasteners are a bit trickier to work with. This type of fastener needs some kind of lubrication, if the tightening shall be just a little uniform. Electrically galvanized fasteners can be treated with a wax like Gleitmo 605, to achieve an easy and fairly controllable tightening. If a higher controllability is needed can the solid lubricant pastes be used.

Hot-dip galvanized fasteners are like the plain fasteners quite controllable as long as they have some kind of lubrication. It is not recommended to use this kind of fastener without any lubrication if the predictability of the tightening is important.

The austenitic steel fasteners how been quite interesting in this test. The requirements of a good lubricant agent is unquestionably present when using this material. The austenitic steel has a high tendency to seize. The main purpose of the lubricant agent is to keep this from happening. The experiments shows that it is not possible to tighten a non-lubricated austenitic fastener to the proof load. Gleitmo 605 made it possible to achieve the proof load, but the friction coefficient was still, way too high. The solid lubricant paste did however show some decent result. Especially G-rapid + had the ability to keep a low friction coefficient, minimize seizing and making the tightening predictable.

Friction Analysis of Bolts

The zinc flake fasters tested in this report, were delivered with a friction controlling top coat. This lead to a fastener with a low friction coefficient and scatter no matter the lubricant were used. This experiment had been more useful if the fasteners had been without the lubricating top coat.

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A1 Appendix 1 – Tightening methods

Tightening factor α_A	$\frac{\Delta F_{\rm M}}{2 \cdot F_{\rm Mm}} = \frac{\alpha_{\rm A} - 1}{\alpha_{\rm A} + 1}$	Tightening technique	Adjusting technique	Remarks	
1,05 to 1,2	±2% to ±10%	Elongation-control- led tightening with ultrasound	Echo time	 Calibrating values n Allow for progressiv I_k/d < 2 Smaller errors with coupling, larger with 	e increase in errors at direct mechanical
1,1 to 1,5	± 5 % to ± 20 %	Mechanical elongation measurement	Adjustment via longitudinal measurement	ience of the bolt is r depends substantia measuring techniqu	of the axial elastic resil- lecessary. The scatter Ily on the accuracy of the e. e increase in errors at
1,2 to 1,4	±9% to ±17%	Yield-controlled tightening, motor or manually operated	Input of the relative torque/rotation-angle coefficient	The scatter in preload mined by the scatter in Here, the bolts are din a design of the bolts for	the bolt yield point. The bolt of F_{Mmin} ; or F_{Mmax} with the tighter
1,2 to 1,4	±9% to ±17%	Angle-controlled tightening, motor or manually operated	Experimental deter- mination of pre-tight- ening torque and angle of rotation (steps)	ing factor a _A therefore tightening techniques.	does not apply to these
1,2 to 1,6	±9% to ±23%	Hydraulic tightening	Adjustment via length or pressure measurement	 Lower values for lor (<i>I</i>_K/<i>d</i> ≥ 5) Higher values for sh 	
1,4 to 1,6	±17 % to ±23 %	Torque-controlled tightening with torque wrench, indicating wrench, or precision tightening spindle with dynamic torque measurement	Experimental deter- mination of required tightening torques on the original bolt- ing part, e.g. by measuring bolt elon- gation	Lower values: large number of cali- bration or check tests (e.g. 20) required; low scatter of the transmitted torque (e.g. ±5%) necessary	Lower values for: • small angles of rotation, i.e. rela- tively stiff joints • relatively soft mating surface ¹) • mating surfaces which are not inclined to "seize", e. g. phosphated or with sufficient lubri- cation
1,6 to 2,0 (friction coeffi- cient class B)	±23% to ±33%	Torque-controlled tightening with torque wrench, indicating wrench, or precision tightening spindle with dynamic torque measurement	Determination of the required tightening torque by estimating the friction coeffi- cient (surface and lubricating condi- tions)	Lower values for: Measuring torque wrenches with steady tightening and for precision tightening spindles	Higher values for: Iarge angles of rotation, i.e. rela- tively resilient joints and fine threads high mating surface hardness combined with a rough surface
1,7 to 2,5 (friction coeffi- cient class A)	±26 % to ±43 %			Higher values for: Signaling or auto- matic tripping torque wrenches	
2,5 to 4	±43 % to ±60 %	Tightening with impact wrench or impact wrench with momentum control	Calibration of the bolt by means of re- tightening torque, made up of the required tightening torque (for the esti- mated friction coeffi- cient) and an additional factor	Lower values for: • large number of cali (re-tightening torque • on the horizontal se characteristic • momentum transfer	e) gment of the bolt

Table A8. Guide values for the tightening factor α_A

¹) Mating surface: Clamped unit its surface contact the tightening unit of the joint (bolt head or nut).

A2 Appendix 2 – Friction coefficients

Table A5. Friction coefficient classes with guide values for different materials/surfaces and lubrication states in bolted joints

Friction coeffi-	Range for	Selection of t	ypical examples for
cient class	μ_{G} and μ_{K}	Material/surfaces	Lubricants
A	0,04 to 0,10	metallically bright black oxide phosphated galvanic coatings such as Zn, Zn/Fe, Zn/Ni Zinc laminated coatings	solid lubricants, such as MoS ₂ , graphite, PTFE, PA, PE, PI in lubricating varnishes, as top coats or in pastes; liquefied wax wax dispersions
в	0,08 to 0,16	metallically bright black oxide phosphated galvanic coatings such as Zn, Zn/Fe, Zn/Ni Zinc laminated coatings Al and Mg alloys	solid lubricants, such as MoS ₂ , graphite, PTFE, PA, PE, PI in lubricating varnishes, as top coats or in pastes; liquefied wax; wax dispersions, greases; oils; delivery state
		hot-galvanized	MoS ₂ ; graphite; wax dispersions
		organic coatings	with integrated solid lubricant or wax dispersion
		austenitic steel	solid lubricants or waxes; pastes
		austenitic steel	wax dispersions, pastes
		metallically bright phosphated	delivery state (lightly oiled)
с	0,14 to 0,24	galvanic coatings such as Zn, Zn/Fe, Zn/Ni Zinc laminated coatings adhesive	none
		austenitic steel	oil
D	0,20 to 0,35	galvanic coatings such as Zn, Zn/Fe; hot-galvanized	none
E	≥ 0,30	galvanic coatings such as Zn/Fe, Zn/Ni austenitic steel AI, Mg alloys	none

The aim is to **achieve** coefficients of friction which fit into the **friction coefficient class B** in order to apply as high a preload as possible with low scatter. This does not automatically mean using the smallest values and that the friction coefficient scatter present corresponds to the class spread. The tables apply at room temperature.

A3 Appendix 3 – Design values for metric fasteners

Table A11. Nominal values for pitch, pitch diameter, stress cross section and cross section at minor diameter, and load $F_{0,2\min}$ for shank bolts with metric standard and fine threads (pitch according to DIN 13-1 and -28; stress cross section and cross section at minor diameter according to DIN 13-28; minimum yield point according to DIN EN ISO 898-1)

Abmessung Size	Steigung Pitch	Flankendurch- messer Pitch diameter	Spannungs- querschnitt Stress cross section	Kern- querschnitt Cross section	Load at	der Mindest-St the minimum y 5 _{0.2 min} = R _{p0.2min}	vield point
			cross section	at minor diameter	Festig	eitsklasse/Stren	gth grade
	Р	<i>d</i> ₂	As	A _{d3}	8.8	10.9	12.9
	mm	mm	mm ²	mm ²	N	N	N
		Metri	sches Regelgewir	nde/Metric standard th	read		
M4	0,7	3,545	8,78	7,749	5600	8 300	9700
M5	0,8	4,480	14.2	12,69	9100	13 300	15600
MG	1	5,350	20,1	17,89	12900	18 900	22100
M7	1	6,350	28,9	26,18	18 500	27 000	32 000
M8	1,25	7,188	36,6	32,84	23 400	34 500	40 50
M10	1,5	9,026	58,0	52,30	37 000	55 000	64 00
M12	1,75	10,863	84,3	76,25	54 000	79 000	93 000
M14	2	12,701	115	104,7	74 000	108 000	Con Standard
M16	2	14,701	157	144,1	100 000		127 000
M 18	2.5	16,376	193	175,1	127 000	148 000	173 000
M 20	2.5	18,376	245	225,2		181 000	212 000
M22	2.5	20,376	303	281,5	162 000	230 000	270 000
M24	3	22,051	353	324,3	200 000	285 000	335 000
M27	3	25,051	459		233 000	330 000	390 000
M 30	3,5	27,727	561	427,1	305 000	430 000	500 000
M 33	3,5	30,727		519,0	370 000	530 000	620 000
M 36	4	33,402	694	647,2	460 000	650 000	760 000
M 39	4	36,402	817	759,3	540 000	770 000	900 000
WI09	4		976	913,0	640 000	920 000	1 070 000
		Me	etrisches Feingew	inde/Metric fine thread	1		
M8	1	7,350	39,2	36,03	25 000	37 000	43 000
M 9	1	8,350	51,0	47,45	32 500	48 000	56 000
M10	1	9,350	64,5	60,45	41 500	61 000	71 000
M 10	1,25	9,188	61,2	56,29	39 000	58 000	67 000
M12	1,25	11,188	92,1	86,03	59 000	87 000	101 000
M12	1,5	11,026	88,1	81,07	56000	83 000	97 000
M 14	1,5	13,026	125	116,1	80 000	118000	138 000
M 16	1,5	15,026	167	157,5	107 000	157 000	184 000
M 18	1,5	17,026	216	205,1	143 000	203 000	238 000
M 18	2	16,701	204	189,8	135 000	192 000	224 000
M 20	1,5	19,026	272	259,0	180 000	255 000	300 000
M 22	1,5	21,026	333	319,2	220 000	315 000	365 000
M 24	1,5	23,026	401	385,7	265 000	375 000	440 000
M24	2	22,701	384	364,6	255 000	360 000	420 000
M 27	1,5	26,026	514	497,2	340 000	485 000	570 000
M27	2	25,701	496	473,2	325 000	465 000	550 000
M 30	1,5	29,026	642	622,8	425 000	600 000	710 000
M 30	2	28,701	621	596,0	410 000	580 000	680 000
M 33	1,5	32,026	784	762,6	520 000	740 000	860 000
M 33	2	31,701	761	732,8	500 000	720 000	840 000
M 36	2	34,701	915	883,8	580 000	830 000	
M 36	3	34,051	865	820,4	570 000	810 000	970 000
the second s	2	37,701	1082	1049,0	714 000	1 010 000	950 000 1 190 000
M 39							

Anmerkung: Kerndurchmesser d_3 siehe Tabelle A12 Note: For the minor diameter d_3 see Table A12

Table A12. Nominal values for pitch, minor diameter, reduced-shank diameter, reduced-shank cross section and load $F_{0,2\min}$ for necked-down bolts with metric standard and fine threads (pitch and minor diameter according to DIN 13-1, -5 to -8; minimum yield point according to DIN EN ISO 898-1)

bmessung Size	Steigung Pitch	Kerndurch- messer Minor diameter	Taillen- durchmesser Reduced-shank diameter	Taillen- querschnitt Reduced- shank cross section	Load at the	Mindest-Street minimum yiel $R_{p0,2min} \cdot \frac{\pi}{4}(0,9 \cdot$	d point
				cross section	Festigkeits	klasse/Strength	grade
	Р	d ₃	$d_{\rm T}=0,9\cdot d_3$	$A_{\rm T} =$	8.8	10.9	12.9
				$\frac{\pi}{4}(0,9\cdot d_3)^2$			
-	mm	mm	mm	mm ²	N	N	N
3		Met	risches Regelgewind	e/Metric standard th	nread		
M4	0,7	3,141	2,83	6,28	4 000	5 900	6900
M5	0,8	4,019	3,62	10,3	6 600	9700	11 300
M6	1	4,773	4,30	14,5	9 300	13600	15900
M7	1	5,773	5,20	21,2	13600	19900	23 300
M 8	1,25	6,466	5,82	26,6	17000	25 000	29 500
M 10	1,5	8,160	7,34	42,4	27 000	40 000	46 500
M 12	1,75	9,853	8,87	61,8	39 500	58 000	68 000
M14	2	11,546	10,4	84,8	54 000	80 000	93 000
M16	2	13,546	12,2	117	75 000	110 000	128 000
M18	2,5	14,933	13,4	142	94 000	133 000	156 000
M 20	2,5	16,933	15,2	182	120 000	171 000	201 000
M 22	2,5	18,933	17,0	228	151 000	214000	250 000
M24	3	20,319	18,3	263	173000	247 000	290 000
M27	3	23,319	21,0	346	228 000	325 000	380 000
M 30	3,5	25,706	23,1	420	275 000	395 000	460 000
M 33	3,5	28,706	25,8	524	345 000	495 000	580 000
M 36	4	31,093	28,0	615	405 000	580 000	680 000
M 39	4	34,093	30,7	739	490 000	700 000	810 000
			Metrisches Feingewir	nde/Metric fine threa	ad		
M8	1	6,773	6,10	29,2	18700	27 500	32 000
M 9	1	7,773	7,00	38,4	24 600	36 000	42 500
M 10	1	8,773	7,90	49,0	31 500	46 000	54 000
M 10	1,25	8,466	7,62	45,6	29000	43 000	50 000
M 12	1,25	10,466	9,42	69,7	44 500	66 000	77 000
M 12	1,5	10,160	9,14	65,7	42 000	62 000	72000
M 14	1,5	12,160	10,94	94,1	60 000	88 000	103 00
M 16	1,5	14,160	12,74	128	82 000	120 000	140 000
M 18	1,5	16,160	14,54	166	110 000	156 000	183 000
M 18	2	15,546	13,99	154	101000	145 000	169 000
M 20	1,5	18,160	16,34	210	138 000	197 000	231 00
M 22	1,5	20,160	18,14	259	171 000	243 000	285 00
M 24	1,5	22,160	19,94	312	206 000	295 000	345 00
M24	2	21,546	19,39	295	195 000	280 000	325 00
M27	1,5	25,160	22,64	403	265 000	380 000	445 000
M27	2	24,546	22,04	383	255 000	360 000	420 000
M 30	1,5	28,160	25,34	504	335 000	475 000	550 000
	2	27,546	24,79	483	320 000	455 000	530 000
M 30		31,160	28,04	618	410 000	580 000	680 00
M 33	1,5		27,49	594	390 000	560 000	650 000
M 33	2	30,546	Committee Co	716	470 000	670 000	780 000
M 36	2	33,546	30,19	664	440 000	620 000	730 000
M 36	3 2	32,319 36,546	29,09 32,89	850	561 000	799 000	935 000
M 39							

A4 Appendix 4 - Calculation of tolerance influence

$$\begin{split} F_{\mathbf{M}} &\coloneqq 54 \text{kN} \\ P &\coloneqq 1.75 \text{nm} \\ d_{2}\text{minustolerance} &\coloneqq 10.679 \text{nm} \\ d_{2}\text{plustolerance} &\coloneqq 10.829 \text{nm} \\ D_{\mathbf{Km}} &\coloneqq \frac{19+12}{2} \text{mm} \\ \mu_{\mathbf{G}} &\coloneqq 0.1. \\ \mu_{\mathbf{K}} &\coloneqq 0.1. \\ M_{\mathbf{a}} &\coloneqq F_{\mathbf{M}} \cdot \left(0.16 \text{ P} + 0.58 \text{ d}_{2}\text{minustolerance} \right) \cdot \mu_{\mathbf{G}} + \frac{D_{\mathbf{Km}}}{2} \cdot \mu_{\mathbf{K}} \right) \\ M_{\mathbf{a}} &\rightarrow 54 \text{ kN} \cdot (0.7432584 \text{nm} + 0.93 \text{ mm} + 0.28 \text{ mm}) = 105.476 \text{N} \cdot \text{m} \\ M_{\mathbf{M}} &\coloneqq F_{\mathbf{M}} \cdot \left(0.16 \text{ P} + 0.58 \text{ d}_{2}\text{plustolerance} \right) \cdot \mu_{\mathbf{G}} + \frac{D_{\mathbf{Km}}}{2} \cdot \mu_{\mathbf{K}} \right) \end{split}$$

 $M_a \rightarrow 54 \text{ kN} \cdot (0.753698 \text{ mm} + 0.93 \text{ mm} + 0.28 \text{ mm}) = 106.04 \text{N} \cdot \text{m}$

 $\frac{(106.04 - 105.47)}{105.476} \cdot 100 = 0.535$

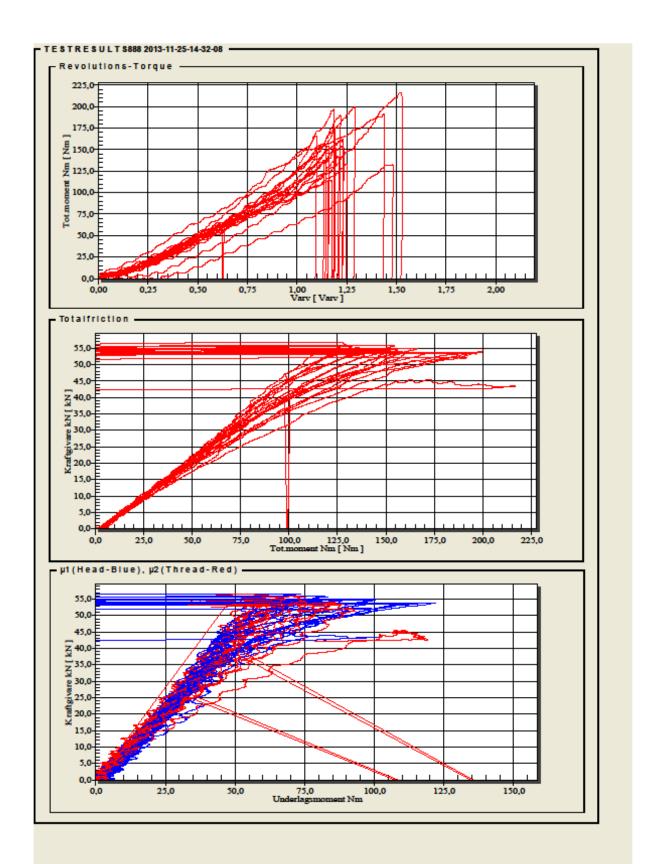
A5 Appendix 5 – Test data

A5.1 Plain without oil

TESTRESULTS 2013-11-25-14-32-08 -----

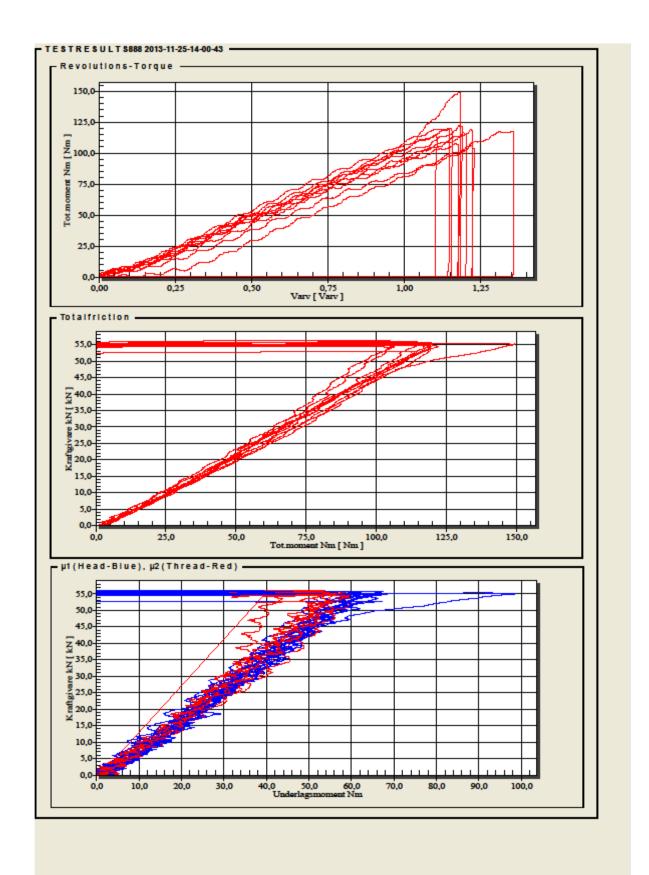
Eachebr - McGonest Prox (NN) µ Ibal µ Ibal µ I µ Z Test data 53,7 195,9 0,16 0,15 0,16 Test data 55,6 133,7 0,14 0,16 0,16 Test data 55,6 133,7 0,14 0,16 0,16 Messure RPM Test data 10 53,6 113,1 0,14 0,12 Proof load: 48,9N Test data 10 53,6 133,2 0,16 0,17 0,16 Misc. test data (Lubrication, wather type etc) 10 53,3 193,6 0,16 0,17 0,16 Dimension M12 Length 13,2 0,16 0,17 0,16 Strength Plath, oll removed 13,2 0,16 0,18 0,18 21 10,23,3 0,16 0,18 0,18 0,18 22 10,23,3 0,16 0,18 0,18 0,18 22 10,22 10,22 0,19 0,12 0,18 <th>Bachelor - frictionitest 1 frinka (km) p tokal p i p z Image (km) p tokal 0,16 0,16 0,16 0,16 1 2 53,2 139,0 0,16 0,17 0,16 2 53,2 139,0 0,14 0,14 0,15 0,15 2 53,2 137,3 0,14 0,14 0,15 0,15 3 63,7 192,4 0,14 0,14 0,15 0,12 3 55,5 132,7 0,14 0,14 0,13 0,14 0,15 4 55,5 137,3 0,14 0,14 0,13 0,14 0,13 9 54,9 134,19 0,14 0,14 0,13 10 53,6 117,5,3 0,17 0,19 0,15 11 54,8 155,9 0,17 0,16 0,12 13 53,9 199,7 0,20 0,19 0,21 11 54,8 195,2 0,16 0,16 0,15 0,15 13 53,9 199,0 0,16</th> <th></th> <th></th> <th></th> <th></th> <th></th> <th></th> <th></th>	Bachelor - frictionitest 1 frinka (km) p tokal p i p z Image (km) p tokal 0,16 0,16 0,16 0,16 1 2 53,2 139,0 0,16 0,17 0,16 2 53,2 139,0 0,14 0,14 0,15 0,15 2 53,2 137,3 0,14 0,14 0,15 0,15 3 63,7 192,4 0,14 0,14 0,15 0,12 3 55,5 132,7 0,14 0,14 0,13 0,14 0,15 4 55,5 137,3 0,14 0,14 0,13 0,14 0,13 9 54,9 134,19 0,14 0,14 0,13 10 53,6 117,5,3 0,17 0,19 0,15 11 54,8 155,9 0,17 0,16 0,12 13 53,9 199,7 0,20 0,19 0,21 11 54,8 195,2 0,16 0,16 0,15 0,15 13 53,9 199,0 0,16							
1 2 5.2 133,0 0.16 0.17 3 5.3,7 196,6 0.16 0.17 0.16 7 For the second seco	2 53,2 139,0 0,16 0,17 3 53,7 196,9 0,16 0,17 0,16 3 53,7 196,9 0,16 0,17 0,16 3 53,7 196,9 0,16 0,17 0,16 3 53,7 196,9 0,16 0,17 0,16 3 53,7 196,9 0,16 0,17 0,16 3 53,7 196,9 0,16 0,17 0,16 3 53,7 196,9 0,16 0,17 0,16 4 5 55,6 132,7 0,14 0,13 0,15 6 55,1 137,3 0,13 0,14 0,14 0,13 9 54,9 132,5 0,14 0,14 0,13 10 53,9 199,7 0,20 0,17 0,15 11 54,8 195,9 0,17 0,16 0,15 11 54,8 199,0 0,20 0,16 0,15 12 54,4 191,8 0,18 <t< th=""><th></th><th></th><th>Fmax [kN]</th><th>Tmax (Nm)</th><th>µ total</th><th>μt</th><th>μ2</th></t<>			Fmax [kN]	Tmax (Nm)	µ total	μt	μ2
3 53,7 196,9 0,16 0,17 0,16 4 56,7 122,4 0,14 0,13 0,15 5 55,6 133,7 0,13 0,14 0,15 7 55,1 137,3 0,13 0,14 0,15 6 55,1 137,3 0,13 0,14 0,15 7 55,1 114,1 0,14 0,15 0,12 7 55,1 114,1 0,14 0,13 0,14 9 54,9 132,5 0,14 0,14 0,15 10 35,6 175,9 0,17 0,16 0,15 11 54,9 162,4 0,15 0,16 0,12 12 54,9 162,4 0,15 0,16 0,15 13 35,9 199,7 0,20 0,16 0,15 14 53,8 190,0 0,16 0,16 0,15 15 54,3 152,3 0,16 0,16 0,15 16 55,5 154,4 0,18 0,16	3 53,7 196,9 0,16 0,17 0,16 4 56,7 129,4 0,14 0,13 0,15 5 55,6 132,7 0,14 0,13 0,15 6 55,1 137,3 0,13 0,14 0,12 7 55,1 114,1 0,14 0,14 0,13 9 54,9 132,5 0,14 0,14 0,13 9 54,9 132,5 0,14 0,14 0,13 9 54,9 132,5 0,14 0,14 0,13 9 54,9 132,5 0,17 0,16 0,16 10 53,6 175,3 0,17 0,17 0,16 11 53,8 199,0 0,16 0,16 0,15 12 54,9 162,4 0,16 0,16 0,15 15 54,3 152,3 0,16 0,16 0,16 14 53,6 190,0 0,16 0,16 0,16 15 54,3 152,3 0,16 0,16	Bachelor - frictiontest	1			0,16	0,16	0,16
4 56,7 129,4 0,14 0,13 - Test data 5 55,6 132,7 0,14 0,12 Test type: Separate Head and Thread friction 10 13 0,14 0,12 14 0,13 Measure RPM 10 10 53,6 175,3 0,14 0,14 0,13 Misc. test data (Lubrication, washer type etc) 10 53,6 175,3 0,17 0,19 0,15 Proof load: 48,9kN 10 54,9 199,7 0,20 0,19 0,21 14 53,8 190,0 0,16 0,16 0,16 0,16 12 54,9 195,2 199,7 0,20 0,17 0,21 14 53,8 190,0 0,16 0,16 0,16 0,16 15 54,3 152,3 0,16 0,14 0,18 0,18 0,12 16 55,1 165,1 0,19 0,21 0,16 0,16 0,16 16 55,2 165,1 0,18 0,18 0,18 0,18 0,18 0,18	4 56,7 129,4 0,14 0,13 - Test data 5 55,6 132,7 0,14 0,13 Test type: Separate Head and Thread friction 5 55,1 137,3 0,14 0,12 Measure RPM 10 5 55,1 114,1 0,14 0,13 0,15 Misc. test data (Lubrication, washer type etc) 10 53,6 175,3 0,17 0,17 0,16 Proof load: 48,9kN 10 54,9 162,4 0,18 0,12 13 53,9 199,7 0,20 0,19 0,21 14 53,8 190,0 0,16 0,16 0,15 15 54,3 152,3 0,16 0,14 0,18 15 54,3 152,3 0,16 0,14 0,18 16 17 55,9 154,4 0,14 0,18 16 16 17 55,9 154,4 0,14 0,18 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 17							
Test data 5 55,6 132,7 0,14 0,13 0,15 Test type: Separate Head and Thread friction 6 55,1 1137,3 0,13 0,14 0,12 Measure RPM 10 10 53,6 172,5 0,14 0,14 0,13 0,15 Misc. test data (Lubrication, washer type etc) 10 53,6 173,2,5 0,14 0,16 0,15 Proof load: 48,9kN 10 54,9 162,4 0,15 0,16 0,12 11 54,8 155,9 0,17 0,17 0,16 0,12 12 54,9 162,4 0,15 0,18 0,12 13 53,9 199,0 0,16 0,16 0,15 14 53,8 190,0 0,16 0,16 0,15 15 54,3 152,3 0,16 0,14 0,13 14 53,8 190,0 0,16 0,16 0,15 15 54,3 152,3 0,16 0,14 0,12 16 55,1 165,4 0,18 0,15	Test data 5 55,6 132,7 0,14 0,13 0,15 Test type: Separate Head and Thread friction 6 55,1 137,3 0,14 0,12 Measure RPM 10 10 34,9 132,2 0,14 0,14 0,13 Misc. test data (Lubrication, washer type etc) 10 53,6 175,3 0,17 0,16 0,15 Proof load: 48,9kN 12 54,9 162,4 0,16 0,16 0,16 9 54,3 155,9 0,17 0,16 0,16 0,16 0,16 11 54,8 190,0 0,16 0,16 0,16 0,16 12 54,9 162,4 0,16 0,16 0,16 13 53,9 194,4 0,14 0,18 0,16 14 53,8 190,0 0,16 0,16 0,16 15 54,3 152,3 0,16 0,16 0,16 16 55,1 196,6 0,18 0,16 0,16 16 52,4 191,8 0,18 0,18 <							
Feb data 6 55,1 137,3 0,13 0,14 0,12 Test type: Separate Head and Thread friction 10 7 55,1 114,1 0,14 0,13 Measure RPM 10 10 10 54,9 132,5 0,14 0,14 0,13 Misc. test data (Lubrication, washer type etc) Proof load: 48,9KN 10 53,6 175,3 0,17 0,19 0,15 Proof load: 48,9KN 11 54,9 162,4 0,15 0,16 0,16 Proof load: 48,9KN 10 55,1 166,1 0,19 0,21 16 14 53,8 190,0 0,16 0,16 0,16 17 16 15 54,3 152,3 0,16 0,16 0,16 0,16 17 14 53,8 190,0 0,16 0,16 0,16 0,16 16 15 54,3 152,3 0,16 0,16 0,16 0,16 12 14 53,5 216,7 0,20 0,17 0,21 20 54,1 153,5 0,	Field data 6 55,1 137,3 0,13 0,14 0,12 Test type: Separate Head and Thread friction 0 14 0,14 0,15 0,12 Measure RPM 10 1 54,8 141,9 0,14 0,13 0,14 0,12 Misc. test data (Lubrication, washer type etc) 10 53,6 175,3 0,17 0,19 0,15 Proof load: 48,9KN 11 54,8 162,4 0,15 0,16 0,12 13 53,9 199,7 0,20 0,19 0,21 14 53,8 190,0 0,16 </td <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>							
Test type: Separate Head and Thread friction Measure RPM 10 Misc. test data (Lubrication, washer type etc) Proof load: 48,9kN 10 53,6 11 54,9 12 54,9 10 53,6 11 53,6 11 53,6 12 53,9 13 53,9 14 53,9 15 54,9 16 17 53,9 18 45,5 21 17 10,863 11,153,6 11,153,6 11,153,6 11,153,6 11,153,6 11,153,6 11,153,6 11,153,6 11,153,6 11,153,6 11,153,6 11,153,6 11,153,6 11,153,6 11,153,6 11,153,6 </td <td>Test type: Separate Head and Thread friction Measure RPM 10 Misc. test data (Lubrication, washer type etc) Proof load: 48,9kN 10 580t data Dimension M12 Length Strength 8 9 54,9 10 53,8 11 54,8 10 53,9 10 53,9 11 54,8 12 54,9 16 55,1 16 17,5 0 10,863 11,75 0 11,863 11,863 11,863 11,863 11,863 11,863 11,863 11,863 11,863 12,25 13,22 14 15,5 16 17,5 <t< td=""><td>- Test data</td><td></td><td></td><td></td><td></td><td></td><td></td></t<></td>	Test type: Separate Head and Thread friction Measure RPM 10 Misc. test data (Lubrication, washer type etc) Proof load: 48,9kN 10 580t data Dimension M12 Length Strength 8 9 54,9 10 53,8 11 54,8 10 53,9 10 53,9 11 54,8 12 54,9 16 55,1 16 17,5 0 10,863 11,75 0 11,863 11,863 11,863 11,863 11,863 11,863 11,863 11,863 11,863 12,25 13,22 14 15,5 16 17,5 <t< td=""><td>- Test data</td><td></td><td></td><td></td><td></td><td></td><td></td></t<>	- Test data						
Test type: Separate Head and Thread fliction Measure RPM 10 Misc. test data (Lubrication, washer type etc) Proof load: 48,9kN 11 54,8 12 54,9 13 53,6 14 15 16 17 18 19 19 10 11 54,8 11 54,8 11 54,8 11 54,9 12 54,9 13 53,9 14 53,8 15 54,3 15 54,3 16 55,9 19 52,4 19 52,4 19 54,1 19 54,1 10,16 10,16 11,15,6 10,18 <td>Test type: Separate Head and Thread friction Measure RPM 10 Misc. test data (Lubrication, washer type etc) Proof load: 48,9kN 10 53,8 11 54,8 12 54,9 13 14 15 16 17 18 19 52,4 19 10 10 11 12 54,9 19 10 10 11 12 54,9 19 52,4 19 52,4 10,65 10,75 10,01 19 52,4 19 52,4 10,863 10,863 10,863 10,863 10,863 10,863 10,863 10,863</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>	Test type: Separate Head and Thread friction Measure RPM 10 Misc. test data (Lubrication, washer type etc) Proof load: 48,9kN 10 53,8 11 54,8 12 54,9 13 14 15 16 17 18 19 52,4 19 10 10 11 12 54,9 19 10 10 11 12 54,9 19 52,4 19 52,4 10,65 10,75 10,01 19 52,4 19 52,4 10,863 10,863 10,863 10,863 10,863 10,863 10,863 10,863							
9 54,9 132,5 0,14 0,14 0,13 Measure RPM 10 53,6 175,3 0,17 0,19 0,15 Misc. test data (Lubrication, washer type etc) 11 54,8 155,9 0,17 0,17 0,18 0,12 Proof load: 48,9kN 12 54,9 162,4 0,15 0,18 0,12 13 53,9 199,7 0,20 0,19 0,21 14 53,8 190,0 0,16 0,16 0,15 14 53,8 190,0 0,16 0,16 0,15 15 54,3 152,3 0,16 0,14 0,18 0,18 15 54,3 152,3 0,16 0,14 0,18 <td>Measure RPM 10 Misc. test data (Lubrication, washer type etc) 10 Proof load: 48,9kN 11 Strength 5 Strength 5 Strength 10 Strength 10 Strength 10 Strength 10 Strength 10 Strength 10 Strength 11 Pitch(P) 1.75 D0 17.25 d2 10,863 dh 13.2 Misc. boil data 0 Statistics 0 Average µ 0.16</td> <td>Test type: Separate Head and Thread Miction</td> <td></td> <td></td> <td></td> <td>-</td> <td>-</td> <td></td>	Measure RPM 10 Misc. test data (Lubrication, washer type etc) 10 Proof load: 48,9kN 11 Strength 5 Strength 5 Strength 10 Strength 10 Strength 10 Strength 10 Strength 10 Strength 10 Strength 11 Pitch(P) 1.75 D0 17.25 d2 10,863 dh 13.2 Misc. boil data 0 Statistics 0 Average µ 0.16	Test type: Separate Head and Thread Miction				-	-	
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Misc. test data (Lubrication, washer type etc) 11 54.8 155.9 0.17 0.17 0.16 Proof load: 48,9KN 12 54.9 162.4 0.15 0.16 0.15 12 54.3 152.3 0.16 0.16 0.15 15 54.3 152.3 0.16 0.14 0.18 14 53.8 190.0 0.16 0.16 0.15 15 55.9 154.4 0.14 0.13 0.16 15 55.9 154.4 0.14 0.13 0.16 0.16 0.17 0.221 0.16 17 55.9 154.4 0.14 0.13 0.16 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.16 0.16 0.15 0.16 0.16 0.16 0.16 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.16 0.16 0.16 0.16 0.18	Misc. test data (Lubrication, washer type etc) 11 54.8 155.9 0,17 0,17 0,16 Proof load: 46,9kN 12 54,9 162,4 0,15 0,18 0,12 13 53,9 199,0 0,16 0,16 0,15 0,16 0,16 14 53,8 190,0 0,16 0,16 0,16 0,16 15 54,3 152,3 0,16 0,14 0,18 16 55,9 154,4 0,14 0,13 0,16 18 45,5 216,7 0,20 0,17 0,25 19 52,4 191,8 0,18 0,18 0,18 21 54,1 153,6 0,18 0,18 0,18 22 0 54,1 153,6 0,18 0,18 24 23 0 0 0 0,16 0,18 22 23 0 0 0 0,18 0,18 23 0 0 0 24 0 0 0 0 0 0 0	Measure RDM 10	10	53,6	175,3	0,17	0,19	0,15
misc. test data (contrador), waker type etc) Proof load: 48,9kN 13 53,9 199,7 0,20 0,19 0,21 14 53,8 190,0 0,16 0,16 0,15 15 54,3 152,3 0,16 0,14 0,18 16 55,1 166,1 0,19 0,21 0,16 17 55,9 154,4 0,14 0,18 0,16 18 45,5 216,7 0,20 0,17 0,25 19 52,4 191,8 0,18 0,18 0,18 20 54,1 153,6 0,18 0,18 0,18 21 21 23 24 23 24 22 2 24 25 26 27 23 2 28 29 30 30 30 30 30 30 30 30 Statistics	misc. test data (Lubrication, washer type etc) Proof load: 48,9kN 13 53,9 199,7 0,20 0,19 0,21 14 53,8 190,0 0,16 0,16 0,15 15 54,3 152,3 0,16 0,14 0,18 16 55,1 166,1 0,19 0,21 0,16 17 55,9 154,4 0,14 0,13 0,16 18 45,5 216,7 0,20 0,17 0,22 19 52,4 191,8 0,18 0,15 0,21 21		11	54,8	155,9	0,17	0,17	0,16
Proof load: 48,9kN 13 53,9 199,7 0,20 0,19 0,21 14 53,8 190,0 0,16 0,16 0,15 15 54,3 152,3 0,16 0,14 0,18 15 55,4 155,4 0,14 0,18 0,16 16 55,5 155,4 0,14 0,18 0,16 17 55,9 154,4 0,14 0,18 0,16 18 45,5 216,7 0,20 0,17 0,25 19 52,4 191,8 0,18 0,18 0,18 21 20 54,1 153,6 0,18 0,18 22 23 24 10,18 0,18 0,18 24 25 26 27 28 29 29 30 30 30 30 30 30 30	Proof load: 48,9kN 13 53,9 199,7 0,20 0,19 0,21 13 53,8 190,0 0,16 0,16 0,16 0,15 14 53,8 190,0 0,16 0,16 0,15 15 54,3 152,3 0,16 0,14 0,18 15 54,3 152,3 0,16 0,16 0,16 16 55,1 166,1 0,19 0,21 0,16 18 45,5 216,7 0,20 0,17 0,25 19 52,4 191,8 0,18 0,15 0,21 20 54,1 153,6 0,18 0,18 0,18 21 20 54,1 153,6 0,18 0,18 22 23 24 10,21 0,18 0,18 24 23 24 10,21 0,21 0,21 25 10,863 0,17,25 29 10,21 0,21 29 30 13,2 152 10,16 10,16 Statistics	Misc, test data (Lubrication, washer type etc)						
14 53,6 0,16 0,16 0,18 15 54,3 152,3 0,16 0,14 0,18 16 55,1 166,1 0,19 0,21 0,16 16 55,1 166,1 0,19 0,21 0,16 17 55,9 154,4 0,14 0,13 0,16 18 45,5 216,7 0,20 0,17 0,25 19 52,4 191,8 0,18 0,18 0,18 20 54,1 153,6 0,18 0,18 0,18 21 2 2 1 2 2 2 23 2 2 2 2 2 2 2 24 2	14 33,6 190,0 0,16 0,14 0,18 15 54,3 152,3 0,16 0,14 0,18 16 55,1 166,1 0,19 0,21 0,16 17 55,9 154,4 0,14 0,18 0,15 0,21 16 55,1 166,1 0,19 0,21 0,16 0,16 0,19 0,21 0,16 17 55,9 154,4 0,14 0,13 0,16 0,15 0,21 0,16 0,16 0,18 0,16 0,16 0,16 0,16<							
16 55,1 166,1 0,19 0,21 0,16 17 55,9 154,4 0,14 0,13 0,16 18 45,5 216,7 0,20 0,17 0,25 19 52,4 191,8 0,18 0,18 0,18 Strength 8 21 1 1 22 20 54,1 153,6 0,18 0,18 0,18 21 21 1 1 1 1 22 23 1 <td< td=""><td>iiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiii</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></td<>	iiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiii							
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Boit data 18 45,5 216,7 0,20 0,17 0,25 19 52,4 191,8 0,18 0,15 0,21 19 52,4 191,8 0,18 0,18 0,18 20 54,1 153,6 0,18 0,18 0,18 21 54,1 153,6 0,18 0,18 0,18 22 23 24 23 24 23 24 25 26 27 28 29 24 29 30 30 30 30 Statistics	Boit data 18 45,5 216,7 0,20 0,17 0,25 Image: Dimension M12 Length 19 52,4 191,8 0,18 0,18 0,18 0,18 Strength 8 22 23 1 1 1 1 22 Strength 8 22 23 1 1 1 1 23 Strength 9 17,25 26 1 </td <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>							
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Dimension M12 Length Strength 8 21 Surf. Treat. Plain, oil removed 23 Head WAF: 18mm 26 Pitch(P) 1.75 D0 17,25 28 d2 10,863 dh 13,2	Dimension M12 Length	Bolt data						
Dimension M12 Length 21 22 22 23 23 24 24 25 24 25 26 27 28 29 29 29 29 30	Dimension M12 Length							
8 22 23 1 1 Surf. Treat. Plain, oil removed 24 25 1 1 Head WAF: 18mm 25 26 27 1 1 Pitch(P) 1.75 D0 17,25 26 1 1 27 d2 10,863 dh 13,2 30 1	Strength 8 Surf. Treat. Plain, oil removed Head WAF: 18mm Pitch(P) 1.75 10,863 dh Misc. boit data Statistics Average μ 0.16	Dimension M12 Length -	21					
Surf. Treat. Plain, oil removed Head WAF: 18mm Pitch(P) 1,75 D0 17,25 d2 10,863 Misc. boil data Statistics Average µ 0,16	Surf. Treat. Plain, oil removed Head WAF: 18mm Pitch(P) 1.75 D0 17,25 d2 10,863 Misc. boilt data Statistics Average µ 0.16		22					
Surf. Treat Plan, on removed Head WAF: 18mm Pitch(P) 1.75 10,863 dn Misc. bolt data Statistics Average µ 0,16	Surf. Treat Plan, on removed Head WAF: 18mm Pitch(P) 1.75 10,863 dh Misc. boit data Statistics Average µ 0.16	Strength ⁸	23					
Subinitian 25 26 Head WAF: 18mm 25 Pitch(P) 1.75 D0 1.75 D0 17,25 d2 10,863 dh Misc. bolt data 30 Statistics Average µ 0,16	Stati. Heat WAF: 18mm Pitch(P) 1.75 D0 17,25 d2 10,863 dh 13,2 Misc. boil data Statistics	Plain, oil removed						
Pitch(P) 1.75 D0 17.25 d2 10.863 dh 13.2 Misc. bolt data	Pitch(P) 1,75 D0 17,25 d2 10,863 dh 13,2 Misc. bolt data Statistics	Sun Treat						
Pitch(P) 1,75 D0 17,25 d2 10,863 dh 13,2 Misc. bolt data 30 30	Pitch(P) 1,75 D0 17,25 d2 10,863 dh 13,2 Misc. bolt data Statistics Average µ 0,16	Head WAF: 18mm						
d2 10,863 dh 13,2 29 30 Misc. bolt data Statistics Statistics 0,16	d2 10,863 dh 13,2 29	1 75 17 25						
d2 10,863 dh 13,2 30 Misc. bolt data Statistics Average μ 0,16	d2 10,863 dh 13,2	Pitch(P) 1,75 D0 17,25						
Misc. bolt data	Misc. bolt data	d2 10,863 db 13,2						
Average µ 0,16	Average µ 0,16							
				Average	μ	0,	16	
				-	-			
				-	-			

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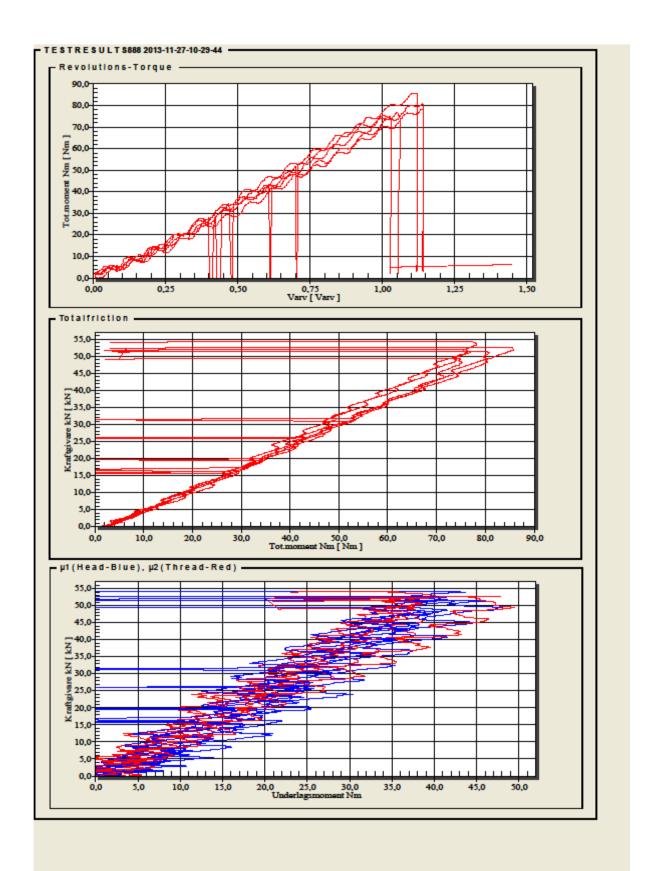
A5.2 Plain oiled

Customer		Fmax IkNI	Tmax (Nm)	µ total	μ1	μ2
Bachelor - frictiontest	1	55,7		0,14	0,14	0,13
	2	54,5		0,12	0,14	0,10
	3	56,2	107,9	0,13	0,13	0,13
	4	55,3		0,14	0,15	0,13
st data	5	54,8		0,14	0,15	0,14
	6	54,9		0,14	0,15	0,14
	7	55,8		0,14	0,14	0,14
Fest type: Separate Head and Thread friction	8	55,7 52,8	116,3 114,4	0,14	0,15	0,12
Aeasure RPM 10	10	55,0	118,9	0,14	0,14	0,14
leasure RPM 10	11					
lisc. test data (Lubrication, washer type etc)	12					
Proof load: 48,9kN	13					
Proditioau. 40,5km	14					
	15					
	16					
	17 18					
t data	19					
c data	20					
Dimension M12 Length	21					
	22					
strength ⁸	23					
Surf.Treat. Plain, olled	24					
Sull Heat	25					
lead WAF: 18mm	26					
1,75 pp 17,25	27 28					
	20					
2 10,863 dh 13,2	30					
lisc. bolt data						
1 Г	 Statistics 					
				_		
		Average	μ	0,	14	
		Standard	deviation µ	0,	01	



A5.3 Plain, oiled with G-Rapid +

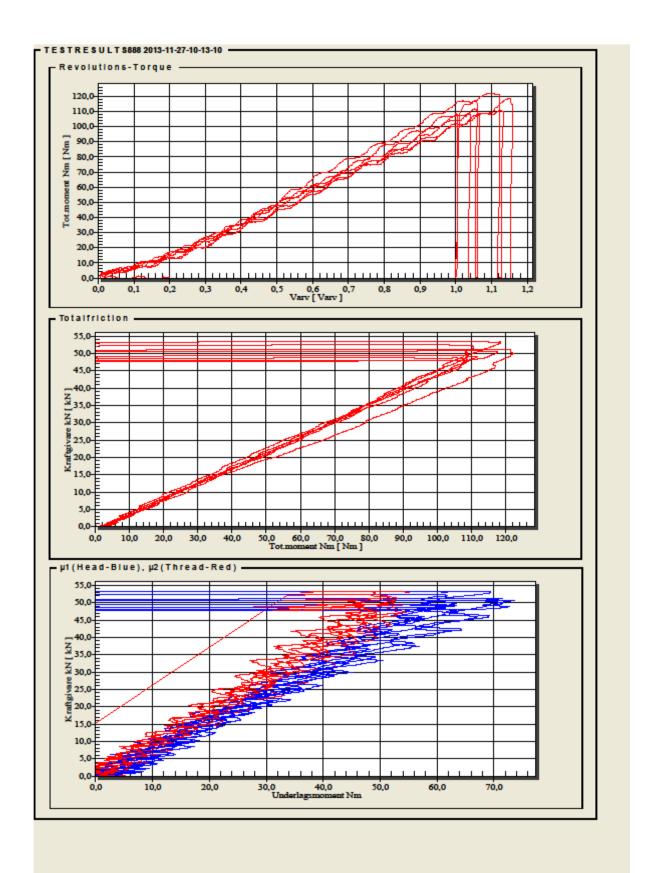
Customer	Concert Public	Terrary (March	tatat		
Bachelor - Frictiontest	Fmax [kN] 1 49,4	Tmax (Nm) 75,4	µ total 0,10	µ1 0,10	μ2 0,10
	2 54,3		0,09	0,10	0,07
	3 52,1		0,09	0,11	0,07
	4 51,6		0,10	0,12	0,07
PS 044	5 52,7	85,9	0,10	0,10	0,10
	7				
	8				_
	9				_
Measure RPM 10	10				
	11				
MISC, lest data (Lubrication, Washer type etc)	12				
ubricated with G-Rapid +	14				_
Floor load. 40,5km	15				
	16				
	17				
	18				_
	20				_
Dimension M12 Length -	21				
	22				
	23				
	24				_
	26				
	27				
	28				
- 10.952 - 13.2	29 30				_
	50				
Misc. bolt data	tistics —				
	Standard	deviation µ	0,0	01	



A5.4 Plain, oiled with Molykote 1000

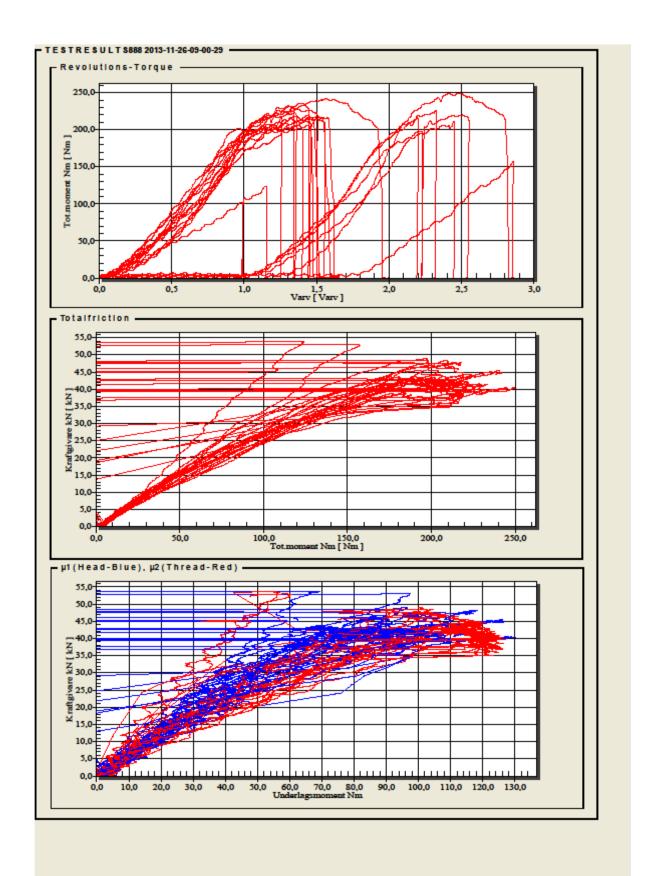
	Ŧ	E	•	Ŧ	P	E	•			Ŧ	•	20	49.	44	 7.4	0	49	-	•	
		-	-			-	-	~	-		-		10			•				

thelor - frictiontest 1 52,5 110,5 0,14 0,15 0,13 2 49,5 111,7 0,14 0,16 0,12 3 48,7 108,9 0,14 0,16 0,13 4 51,2 122,2 0,16 0,19 0,14	Customer	Fr	nax [kN]	Tmax (Nm)	µ total	μt	μ2
3 48,7 108,9 0,14 0,16 0,13 4 51,2 122,2 0,16 0,19 0,14 5 50,8 117,6 0,15 0,18 0,11 6 53,4 118,6 0,14 0,17 0,11 6 53,4 118,6 0,14 0,17 0,11 7 3 118,6 0,14 0,17 0,11 6 53,4 118,6 0,14 0,17 0,11 7 3 118,6 0,14 0,17 0,11 8 9 1 1 1 1 1 10 10 1 1 1 1 1 11 11 1 1 1 1 1 1 11 11 1	Bachelor - frictiontest	1	52,5	110,5	0,14	0,15	0,13
4 51,2 122,2 0,16 0,19 0,14 sta 5 50,8 117,6 0,15 0,11 0,11 type: Separate Head and Thread friction 0 10 10 10 10 10 10 10 11 10 11 10 11 10 11							
sta \$ \$0,8 \$117,6 \$0,15 \$0,18 \$0,11 \$							
sta 6 53,4 118,6 0,14 0,17 0,11 type: Separate Head and Thread friction 10 1						-	-
type: Separate Head and Thread friction ure RPM 10 test data (Lubrication, washer type etc) ricated with Molykole 1000 of load: 48,9kN treat Plain, oiled WAF: 18mm (P) 1,75 D0 17,25 10,863 dh 13,2 bolt data	ata						
type: Separate Head and Thread Miction ure RPM 10 test data (Lubrication, washer type etc) ricaled with Molykote 1000 of load: 48,9kN ta mision M12 Length 11 10 11 11 11 12 11 13 14 14 15 15 16 16 11 17 16 18 16 19 11 20 11 21 11 22 11 23 11 24 11 25 11 26 11 27 11 28 11 29 11 10,863 13,2 10 13,2 10 11 11,75 10 10,863 13,2 10,863 13,2 10 11 11,10			00,4	110,0	0,14	0,17	9,11
yper opposite risk of r	type: Separate Head and Thread figtion						
ure RPM 10 10 11 <	ype. Separate nead and Thread Incoon						
11 1 1 test data (Lubrication, washer type etc) 12 1 ricated with Molykote 1000 13 1 of load: 49,9kN 11 1 1 a 11 12 1 1 nsion M12 Length 16 1 1 gth 8 19 1 1 1 1 18 19 1 1 1 1 1 gth 8 20 1 1 1 1 1 19 21 23 1 </td <td>10</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>	10						
test data (Lubrication, washer type etc) iticated with Molykote 1000 of load: 48,9kN a nsion M12 Length 11 iticated with Molykote 1000 M12 Length gth 8 iticated with Molykote 1000 M12 Length iticated with Molykote 1000 WAF: 18mm P) 17.75 D0 17.25 10,863 iticate Mata Statistics Average µ 0,15							
totated with Molykote 1000 13 13 14 15 fload: 48,9kN 14 15 16 17 a 18 19 10 11 a 19 10 11 11 gth 8 19 10 11 gth 8 21 11 11 20 10 17,25 10 17,25 10,863 13,2 29 10 10 bolt data Statistics 10,15 11	est data (Lubrication, washer type etc)						
r/load: 48,9kN 14 14 14 14 1 1 15 1 1 16 1 1 17 1 1 18 1 1 19 1 1 20 1 1 21 1 1 22 1 1 23 1 1 24 1 1 25 1 1 26 1 1 27 1 1 28 1 1 29 1 1 30 1 1 Statistics		13					
15 1 1 15 16 1 16 1 1 17 1 1 18 1 1 20 1 1 21 1 1 22 1 1 23 1 1 24 1 1 25 1 1 26 1 1 27 1 1 10,863 13,2 30 Statistics	ad: 48.9kN	14					
17 18 19 11 18 19 11 11 19 11 11 11 20 11 11 11 21 11 11 11 22 11 11 11 23 11 11 11 24 11 11 11 25 11 11 11 26 11 11 11 27 11 11 11 28 11 11 11 29 11 11 11 30 11 11 11 Statistics							
1 M12 Length - 19 -							
n M12 Length - 20							
ton M12 Length							
Alon M12 Length h 8 22 23 24 25 24 25 26 27 26 27 28 29 30 10,863 dh 13,2							
an 22 1 1 base 23 1 1 WAF: 18mm 24 1 1 1,75 D0 17,25 26 1 10,863 dh 13,2 29 1 Net data Statistics 1 1							
8 23 10,863 13,2 data Statistics	n M12 Length -						
t Plain, olied WAF: 18mm 1.75 D0 17.25 10,863 dh 13.2 data Statistics Average μ 0,15							
WAF: 18mm 25 10,863 11,25 10,863 0 13,2 data Statistics	°						
WAF: 18mm 26 27 28 10,863 dh 13,2 30 10 data Statistics 9 10,15 10,15	Plain, olled						
1.75 D0 17.25 10,863 dh 13,2 data Statistics Average μ 0,15							
1.75 D0 17,25 10,863 dh 13,2 iata - Statistics	WAF: 18mm						
29 10,863 dh 13,2 ata Statistics Average μ	1.75 pp 17.25						
10,863 dh 13,2 . 30	00 11,20						
Average µ 0,15	10,863 dh 13,2						
Average µ 0,15		. 30					
Average µ 0.15	data						
		- Statistics					
					0	15	
Standard deviation µ 0,01			Average	۴	Ľ.		
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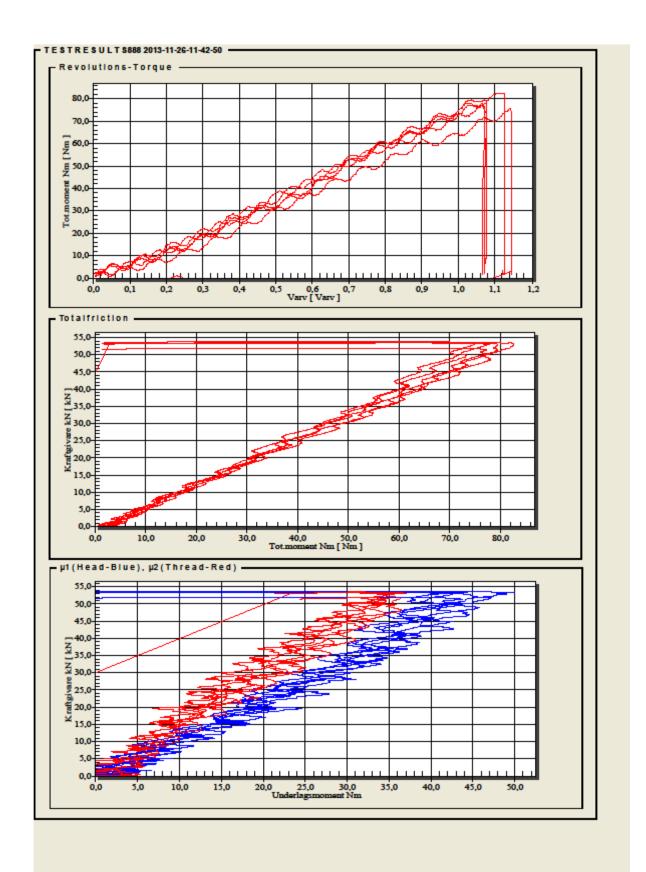
A5.5 FZB, no lubrication

Customer					
Pachalas Malasiasi		Tmax (Nm)	µ total	µ1	μ2
	1 53,8		0,14	0,17	0,11
	2 45,5	242,2	0,29	0,25	0,35
	3 48,9	220,1	0,21	0,19	0,24
	4 41,6	219,3	0,26	0,21	0,33
3.2	5 40,5	249,7	0,31	0,24	0,38
	6 53,1	157,6	0,20	0,26	0,13
	7 44,3	225,4	0,28	0,23	0,34
The second of th	8 38,8	206,3	0,28	0,22	0,35
	9 47,7 10 46,7	216,3	0,26	0,27	0,25
DOULE INFINI		217,1	0,22	0,20	0,26
	11 42,5 12 42,7	211,6	0,20	0,21	0,30
C. LESI GALA (LUDIICAUDI), WASHEL IVDE ELC)	13 42,2	211,0	0,24	0,20	0,30
o lubrication	14 43,1	210,8	0,20	0,18	0,31
0011080.40,581	15 48,3	218,1	0,24	0,31	0,23
	16 42,1	233,5	0,27	0,21	0,33
	17 43,9	235,5	0,27	0,21	0,33
		210,9	0,20	0,22	0,31
					-
	19 42,7	228,3	0,29	0,27	0,30
	20 43,3	232,4	0,29	0,24	0,35
conger	21				
	22				_
ingui	23				
Transf F4D	24				_
	25				
	26				
4.7.6	27				_
	28 29				
10.952					
	30				
bolt data					
- Sta	atistics —				
	Average (μ	0,	25	
	Chan do and	deviation μ	0,	u4	
	Standard				
	Stanoaro				
	standard				



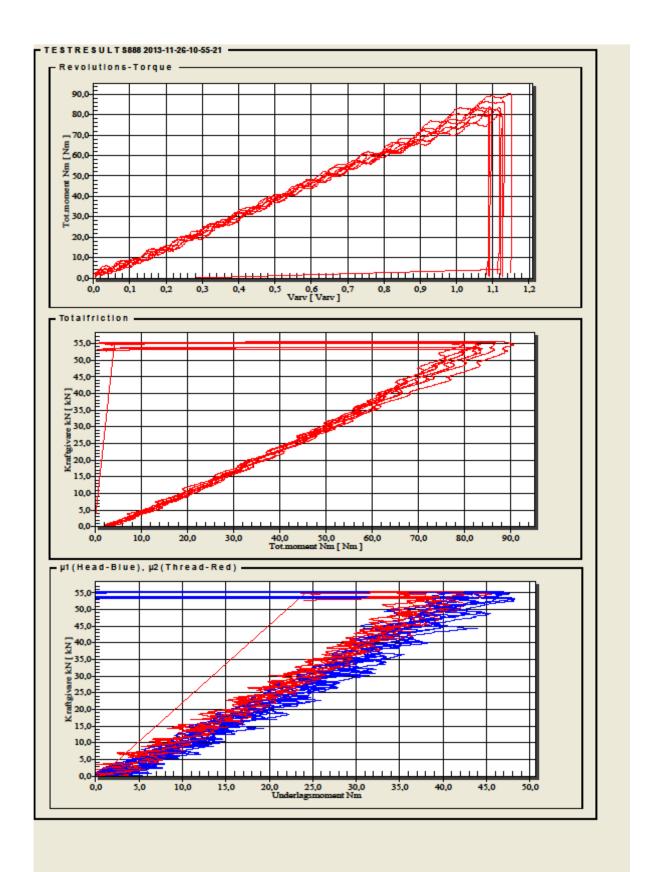
A5.6 FZB, with G-Rapid +

Customer		Empy Phil	Terrar (blas)	u total		
Bachelor - frictiontest	1	Fmax [kN] 53,8	Tmax (Nm) 75,5	µ total 0,09	µ1 0,12	μ2 0,06
	2	53,6		0,09	0,12	0,06
	3	53,5		0,09	0,12	0,06
	4	51,8		0,09	0,11	0,08
est data	5	53,4	79,5	0,09	0,12	0,06
col data	6					
	7					
Test type: Separate Head and Thread friction	8					
Measure RDM 10	9					
Measure RPM 10	10					
	12					
Misc. test data (Lubrication, washer type etc)	13					
Lubricated with G-Rapid + Proof load: 48,9kN	14					
	15					
	16					
	17					
ali dala	18					
olt data	19 20					
Dimension M12 Length -	20					
Dimension Length	22					
Strength ⁸	23					
	24					
Sunneau	25					
Head WAP: 18mm	26					
1.75	27					
Pitch(P) 1.75 D0 17,25	28 29					
d2 10,863 dh 13,2	30					
Misc. bolt data						
	Statistic	5				
		Average	u	0,	09	
		Standard	deviation µ	0,	00	



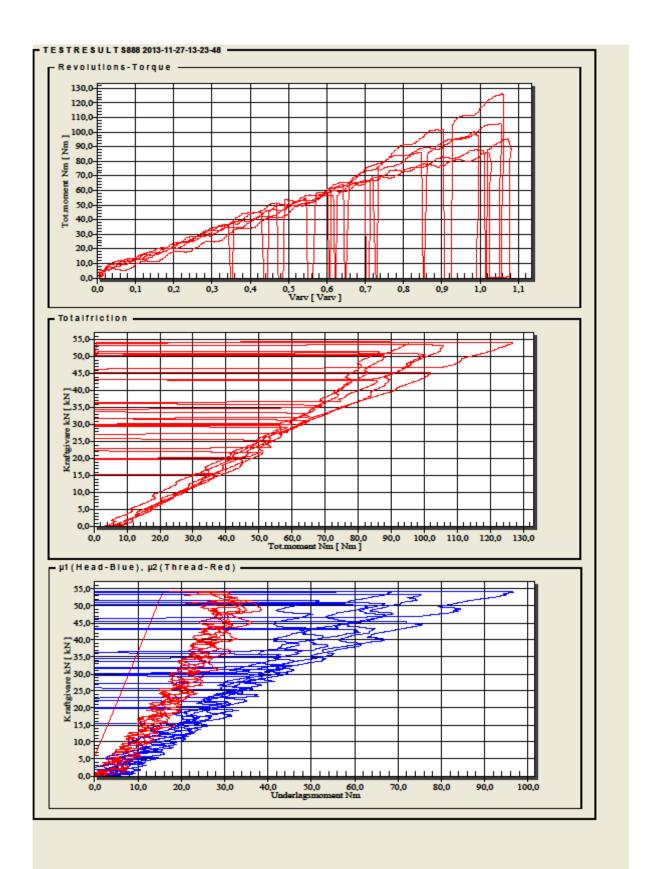
A5.7 FZB, with Molykote 1000

		sults				
Customer		Emax IkM	Tmax (Nm)	µ total	μt	μ2
Bachelor - Frictiontest	1	55,3		0,09	0,10	0,09
	2	53,9		0,09	0,10	0,05
	3	55,2		0,09	0,10	0,08
	4	55,2		0,09	0,10	0,08
	5	55,6		0,10	0,10	0,08
st data	6	53,7		0,10	0,12	0,10
		53,4		0,10	0,12	0,07
	8					
Fest type: Separate Head and Thread friction	9	55,1	82,4	0,09	0,12	0,07
Aeasure RPM 10	10					
Measure RPM 10	11					
	12					
lisc. test data (Lubrication, washer type etc)	13					
Lubricated with Molykote 1000 Proof load: 48,9kN	14					
Proof load: 48,9kN						
	15					
	16					
	17					
	18					
it data	19					
	20					
Dimension M12 Length -	21					
	22					
Strength ⁸	23					
Surf.Treat. FZB	24					
Sun meac	25					
lead WAP: 18mm	26					
	27					
Pitch(P) 1,75 D0 17,25	28					
	29					
12 10,863 dh 13,2	30					
lice helt data						
Alisc. bolt data						
	- Statistic	\$				
		Average	u	0.	10	
		Allelaye	-	Ľ		
		Standard	deviation µ	0,	01	
				Ľ		



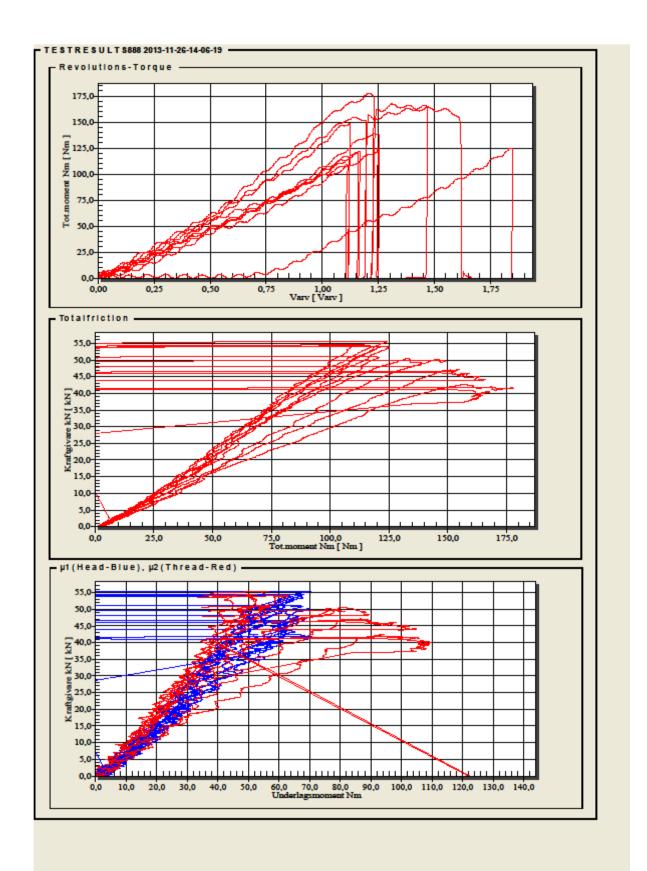
A5.8 FZB, with Gleitmo 605

Customer						
Bachelor - Frictionstest			Tmax (Nm)	µ total	μ1	μ2
	1	54,4 51,1		0,11	0,17	0,05
	3	54,3		0,14	0,20	0,07
	4	51,7		0,12	0,16	0,07
fest data	5	53,5	105,8	0,13	0,19	0,07
	6					
Test type: Separate Head and Thread friction	8					
	9					
Measure RPM 10	10					
Mice fort data (Lubdeation, warber has als)	12					
Misc. test data (Lubrication, washer type etc) Lubricated with Gleitmo 605 1:5	13					
Proof load: 48,9kN	14					
	15 16					
	17					
	18					
oit data	19					
Dimension M12 Length -	20					
	22					
Strength ⁸	23					
Surf.Treat FZB	24 25					
	25					
	27					
Pttch(P) 1.75 D0 17,25	28					
d2 10,863 dh 13,2	29 30					
	. 30					
Misc. bolt data	-					
	- Statistic	5				
					10	
		Average	μ	U.	12	
		Standard	deviation µ	0,	01	



A5.9 FZV, no lubrication

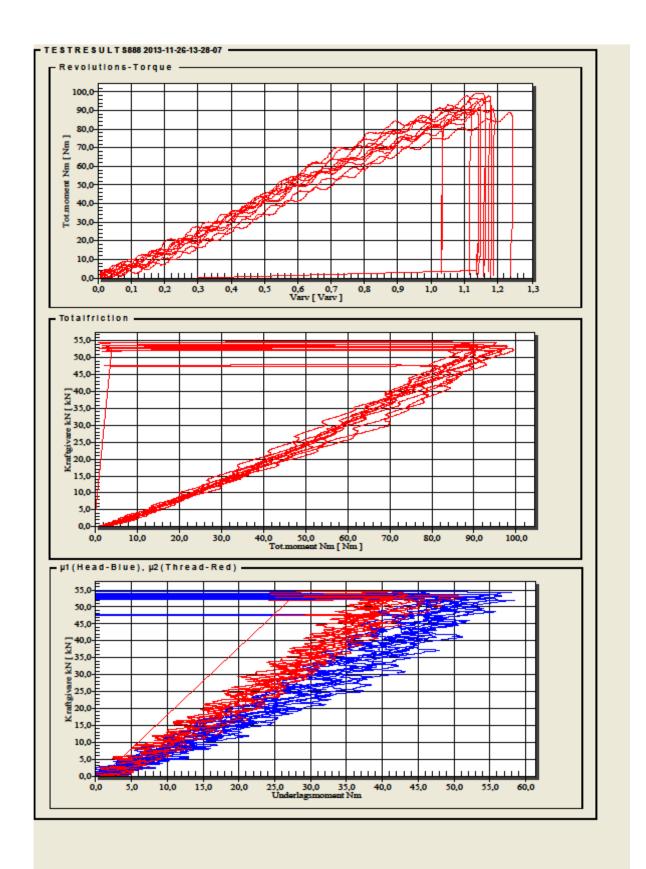
	F Test res					
Customer		Fmax IkNI	Tmax (Nm)	µ total	µ1	μ2
Bachelor - Frictiontest	1	47,1		0,20	0,21	0,19
	2	50,5		0,15	0,14	0,17
	3	54,2		0,14	0,15	0,13
	4	54,0		0,13	0,15	0,10
and state	5	55,5		0,13	0,15	0,12
est data	6	51,1	120,9	0,15	0,17	0,12
	7	54,1		0,14	0,15	0,13
Test type: Separate Head and Thread friction	8	54,6		0,13	0,15	0,11
rescrype. Separate nead and Thread Incoon	9	50,2		0,17	0,18	0,16
Measure RDM 10	10	42,6		0,23	0,18	0,29
Measure RPM 10	11					
	12					
Misc. test data (Lubrication, washer type etc)	13					
No lubrication, oil remove on nut	14					
Proof load: 48,9kN	15					
	16					
	17					
	18					
oit data	19					
oli data	20					
Dimension M12 Length	20					
Dimension M12 Length -						
Strength 8	22					
Suengui	23					
Surf.Treat. FZV	24 25					
Head WAP: 18mm	26					
Ptteb(P) 1,75 pp 17,25	27					
Pltch(P) 1,75 D0 17,25	28					
d2 10,863 dh 13,2	29					
	. 30					
Misc. bolt data						
	- Statistic	<				
	Guidelio					
		Average	μ	0,	16	
				_		
		Standard	deviation µ	0,	03	



A5.10 FZV, oiled

TESTRESULTS 2013-11-26-13-28-07 -----

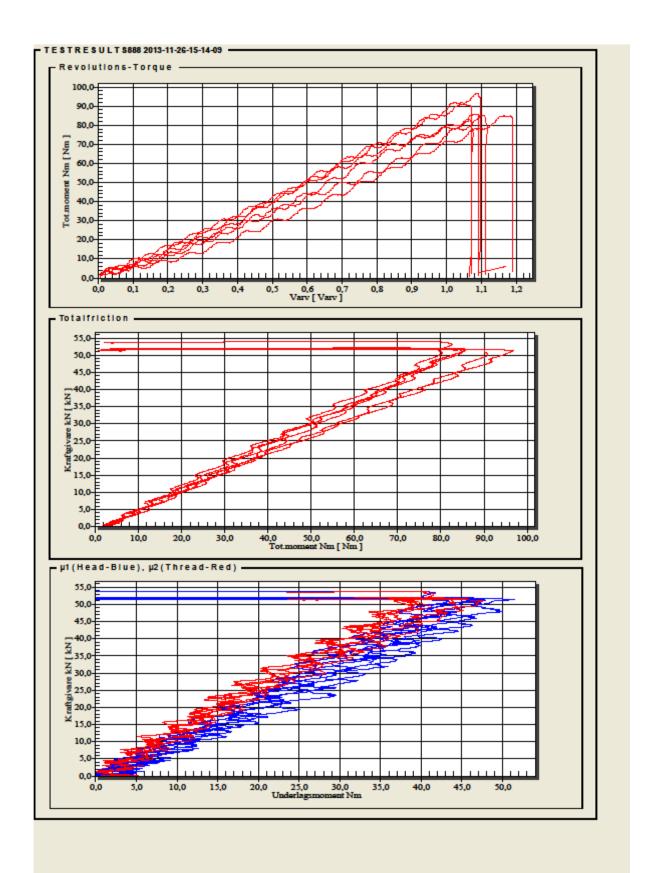
2 52,9 99,4 0,12 0,15 0,09 3 52,1 96,7 0,11 0,14 0,09 4 54,6 95,3 0,11 0,14 0,09 4 54,6 95,3 0,11 0,14 0,08 5 53,8 97,9 0,12 0,15 0,08 6 53,9 90,8 0,13 0,16 0,09 7 53,2 91,0 0,11 0,13 0,08 8 53,4 97,9 0,12 0,13 0,011 9 54,7 88,9 0,11 0,11 0,10 9 54,7 88,9 0,12 0,13 0,10 10 10 52,4 94,9 0,12 0,13 0,10	Bashalar Eristianiart	Fmax [kN]		µ total	μt	μ2
3 52,1 96,7 0,11 0,14 0,09 4 54,6 95,3 0,11 0,14 0,08 5 53,8 97,9 0,12 0,15 0,08 6 53,9 90,8 0,13 0,16 0,09 7 53,2 91,0 0,11 0,13 0,08 8 53,4 97,9 0,12 0,13 0,11 0,10 10 52,4 94,9 0,12 0,13 0,10 11 10 10 52,4 94,9 0,12 0,13 0,10 11	Bachelor - Frictiontest					
4 54,6 95,3 0,11 0,14 0,08 a 5 53,8 97,9 0,12 0,15 0,08 ype: Separate Head and Thread friction 6 53,2 91,0 0,11 0,13 0,08 a 10 52,4 94,9 0,12 0,13 0,11 9 54,7 88,9 0,11 0,13 0,10 10 52,4 94,9 0,12 0,13 0,10 11 9 54,7 88,9 0,11 0,11 0,10 10 52,4 94,9 0,12 0,13 0,10 11 9 54,7 88,9 0,11 0,10 11 10 52,4 94,9 0,12 0,13 0,10 12 13 14 14 15 16 17 18 16 17 18 16 12 17 18 12 12 16 17 12 17 12 16 17 16 17 16 17 16 17		-				
a						
a 6 53,9 90,8 0,13 0,16 0,09 ype: Separate Head and Thread friction 10 7 53,2 91,0 0,11 0,13 0,08 are RPM 10 10 52,4 94,9 0,12 0,13 0,11 set data (Lubrication, washer type etc) 10 52,4 94,9 0,12 0,13 0,10 11 11 12 13 14 12 13 14 12 13 14 12 13 14 16 16 17 18 16 17 18 16 17 18 16 17 18 16 17 18 16 17 18 16 17 18 16 17 18 17 18 17 18 17 18 17 18 17 18 17 18 17 17 18 17 18 17 18 17 18 19 10 12 12 14 17 12 12 12 12 12 <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>						
ype: Separate Head and Thread friction ire RPM 10 10 est data (Lubrication, washer type etc) out lubrication out lubrication f load: 48,9kN 11 12 13 14 15 16 17 18 19 20 21 18 19 20 21 18 19 20 21 22 23 24 25 17.25 10,863 13,2 00 10,863 13,2 010,863 13,2 0 10,863 13,2 0 10,863 11,25 12,30 13,2 10,863 11,25 12,30 1	a					
re: Separate Head and Thread friction re RPM 10 est data (Lubrication, washer type etc) out lubrication fload: 48,9kN 11 12 13 14 15 16 17 18 19 20 21 18 22 23 24 25 26 27 13,2 10,863 13,2 0 10,863 13,2 0 10,863 13,2 0 10,863 13,2 0 0 10,863 13,2 0 10,863 11,75 10,863 13,2 0 14 15 16 17,75 10,01						
9 54,7 88,9 0,11 0,11 0,10 10 52,4 94,9 0,12 0,13 0,10 11 1 1 1 1 1 1 1 10 act 48,9kN 10 52,4 94,9 0,12 0,13 0,10 11 11 11 11 11 11 11 11 11 10 act 48,9kN 11 </td <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>						
IP ID ID <th< td=""><td>ype: Separate Head and Thread friction</td><td></td><td></td><td></td><td></td><td></td></th<>	ype: Separate Head and Thread friction					
a set data (Lubrication, washer type etc) out lubrication out lubrication f load: 48,9kN a gth 8 a gth 8 a gth 8 a gth 8 a bolt data a bolt data Average µ 0.12						
est data (Lubrication, washer type etc) out lubrication rioad: 48,9kN a nsion M12 Length gth 8 reat. FZV WAP: 18mm P) 17.5 10,863 dh adata Variation Variation Statistics Average μ 0,12	III III III III III III III III III II		94,9	0,12	0,13	0,10
al data 13 14 13 14 10 ad: 48,9kN 14 15 14 15 14 15 16 17 16 16 17 18 19 11 18 19 10 11 11 19 20 11 11 11 12 11 11 11 11 11 12 12 11 11 11 11 11 16 17 10 11						
a 14 1 1 a 11 15 1 a 15 1 1 a 15 1 1 a 11 15 1 a 11 15 1 a 11 15 1 a 11 15 1 a 12 10 1 bolt data 13.2 1 1 Statistics 1 1	est data (Lubrication, washer type etc)					
15 16 16 17 16 17 17 18 19 11 20 11 21 11 22 11 23 11 24 11 25 11 26 11 27 11 28 11 29 11 30 11 30 11	ut lubrication					
16 1 1 17 1 1 18 1 1 19 1 1 20 1 1 21 1 1 22 1 1 23 1 1 24 25 1 25 1 1 26 1 1 27 1 1 28 1 1 29 1 1 30 1 1 Statistics	load: 48,9kN					
17 18 18 19 19 10 10 11 10 12 10 12 11 12 11 12 11 12 11 12 11 12 11 12 11 12 11 12 11 13 110,863 13,2 110,863 13,2 110,863 13,2 110,863 13,2 110,863 13,2 110,863 13,2 110,863 13,2 110,863 13,2 110,863 13,2 110,863 13,2 110,863 13,2 110,863 13,2 110,863 13,2 110,90 13,2 110,90 13,2 110,90 13,2 110,90 13,2 110,90						
18 1 19 1 20 1 21 1 22 1 23 1 24 1 25 1 26 1 27 1 10,863 th 113,2 1 Nt data 1 Statistics 1 0,12 1						
ion M12 Length						
Ion M12 Length						
inn M12 Length		19				
8 at. FZV WAP: 18mm 1,75 10,863 dh 13,2 Xuar Statistics		20				
8 22 23 1 1 FZV WAP: 18mm 26 1 1 1,75 D0 17,25 28 1 1 10,863 dh 13,2 30 1 1 Statistics	M12 Length -	21				
FZV 23 10,863 11,25 10,863 113,2 113,2 10,863 113,2 Average µ 0,12		22				
FZV 24 10,863 13,2 data Statistics 0,12	8	23				
WAP: 18mm 25 10,863 11,725 10,863 113,2 28 10,12 data Statistics 10,12	57/					
WAP: 18mm 26 10,000 10,063 17,25 28 10,000 10,063 13,2 10,000 10,000 data Statistics 10,12	t ^{F2V}					
1,75 D0 17,25 10,863 dh 13,2 30 Statistics Average µ 0,12	WAD: 19mm					
1,75 D0 17,25 10,863 dh 13,2 iata Statistics	WAP. 10mm					
10,863 dh 13,2 sata Statistics Average µ 0,12	1.75 pp 17.25					
10,863 dh 13,2 data Statistics Average µ 0,12	00 00					
ta	10.863 db 13,2					
Average µ 0,12		30	I			
Average µ 0,12	tata					
Average µ 0,12	_ 9	tatictics				
					12	
Standard deviation µ 0,01		Average	μ.	υ,	12	
Standard deviation μ		-			01	
	I	Standar	d deviation µ	υ,		



A5.11 FZV, G-rapid +

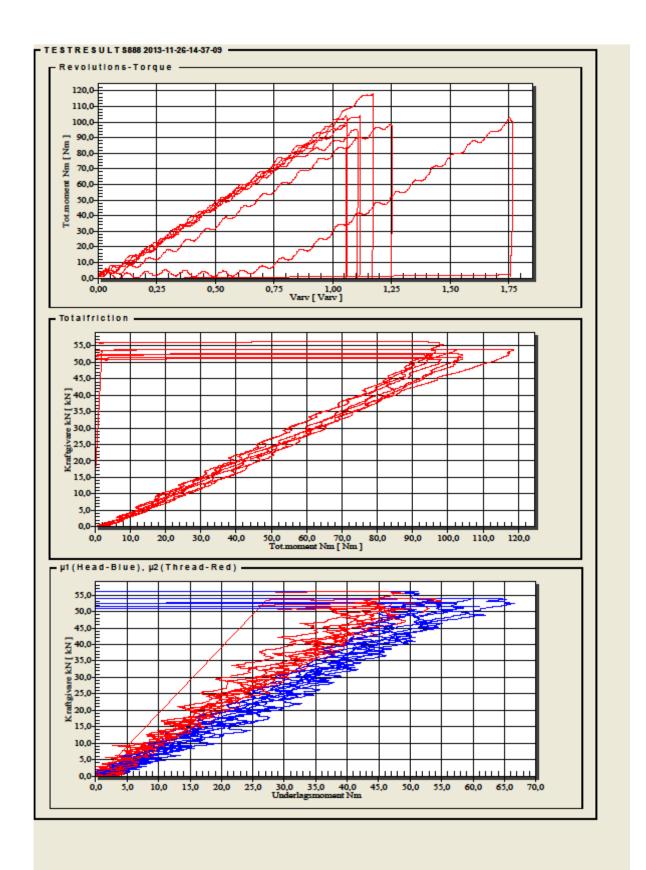
- TESTRESULTS 2013-11-26-15-14-09 -----

1 3 30, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	1 3 3,9 82,8 0,10 0,13 0,07 3 53,9 82,8 0,10 0,11 0,09 4 51,6 90,8 0,10 0,11 0,09 4 51,6 90,8 0,10 0,11 0,09 4 51,6 90,8 0,11 0,13 0,10 5 51,7 85,3 0,10 0,11 0,08 6 51,8 96,8 0,12 0,13 0,10 7 5 56,8 0,12 0,13 0,10 8 9 1 1 1 1 1 10 10 1 1 1 1 1 1 11 1 <th>ustomer</th> <th></th> <th></th> <th>Tmax (Nm)</th> <th>µ total</th> <th>μt</th> <th>μ2</th>	ustomer			Tmax (Nm)	µ total	μt	μ2
3 53,9 62,8 0,10 0,11 0,09 4 51,6 90,8 0,11 0,13 0,10 be: Separate Head and Thread friction 6 51,8 96,8 0,12 0,13 0,10 6 51,8 96,8 0,12 0,13 0,10 0	3 53.9 82,8 0,10 0,11 0,09 4 51,6 90,8 0,11 0,13 0,10 ype: Separate Head and Thread friction 10 1 0.08 6 51,8 96,8 0,12 0,13 0,10 ype: Separate Head and Thread friction 10 1 0.11 0,08 6 51,8 96,8 0,12 0,13 0,10 reat data (Lubrication, washer type etc) 10 1 </th <th>achelor - Frictiontest</th> <th></th> <th></th> <th></th> <th></th> <th></th> <th></th>	achelor - Frictiontest						
4 \$1,6 90,8 0,11 0,13 0,10 be: Separate Head and Thread Miction \$5 \$1,7 85,3 0,10 0,11 0,08 be: Separate Head and Thread Miction 10 \$1 </td <td>4 51,5 90,8 0,11 0,13 0,10 ia </td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>	4 51,5 90,8 0,11 0,13 0,10 ia							
s 5 51,7 85,3 0,10 0,11 0,08 be: Separate Head and Thread friction 6 51,8 96,8 0,12 0,13 0,10 ated with G-rapid + load: 10 11	a s \$1,7 85,3 0,10 0,11 0,08 ype: Separate Head and Thread friction 10 1 0,13 0,10 ire RPM 10 10 10 10 10 10 iest data (Lubrication, washer type etc) 12 11 11 11 11 11 icated with G-rapid + 12 13 14 15 16 16 17 a main field 11 14 15 16 16 16 17 16 16 17 18 16 17 18 16 17 18 16 17 16 17 17 16 17 17 16 17 17 16 17 17 16 17 17 16 17 17 16 17 17 17 16 17 17 16 17 17 16 17 17 16 17 17 16 17 17 16 17 17 16 17 17 16 17 17<					-	-	
be: Separate Head and Thread fitction e RPM 10 ated with G-rapid + ioad: 48,9kN ioad: 40,9kN <	ype: Separate Head and Thread friction ire RPM 10 iest data (Lubrication, washer type etc) icated with G-rapid + if load: 48,9kN a nsion M12 Length ight 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 10.863 11.2 10.863 11.3.2 Statistics							
be: Separate Head and Thread friction e RPM 10 atd (Lubrication, washer type etc) ated with G-rapid + load: 48,9kN ioad: 48,9kN <	ype: Separate Head and Thread fitction are RPM 10 test data (Lubrication, washer type etc) totated with G-rapid + if load: 48,9kN a a a nsion M12 Length - gth 8 FZV WAP: 18mm P) 1,75 D0 17.25 10,863 dh 13,2 boit data Statistics Average µ 0,11	Gala		51,8	96,8	0,12	0,13	0,10
9	yper corporate finate and finate an							
e RPM 10 10 10 11	III IIII IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII	st type: Separate Head and Thread friction						
at data (Lubrication, washer type etc) ated with G-rapid + load: 48,9kN ioad: 1	Lubrication, washer type etc) toated with G-rapid + of load: 48,9kN a a a a nsion M12 gth 6 freat F2V WAP: 18mm P) 17.25 10.863 dh J0.863 dh J11 1 Average µ 0,11	asure RDM 10						
added with G-rapid + load: 45,9kN 13 14 15 idon M12 Length 16 17 18 idon M12 Length 12 13 14 if 12 14 15 idon M12 Length 12 14 15 idon M12 Length 12 14 15 idon M12 Length 12 10 10 idon M12 Length 12 10 10 idon M12 Length 12 10 10 idon M12 Length 13 14 10 10 idon M12 Length 13 14 16 10 idon M12 Length 12 10 10 10 idon M12 Length 17 18 10 10 idon M13,2 13,2 26 10 10 id data 13,2 13 10 10 10 id data 13,2 13,2 10 10 10 id data 13,2 13,2 10 10 10 id data 13,2 13,2 <	load (Lubricator), Washer type etc) icated with G-rapid + fload: 48,9kN a a nsion M12 Length gth 8 reat. FZV WAP: 18mm P) 17.25 10,863 dh J13,2 Statistics							
aded with G-rapid + load: 48,9kN 14 1 1 iload: 48,9kN 15 1 1 iload: 48,9kN 15 1 1 iload: 48,9kN 15 1 1 iload: 48,9kN 14 1 1 1 iload: 48,9kN 15 1 1 1 iload: 48,9kN 13,2 20 1 1 1 iload: 48,9kN 12 1 1 1 1 1 iload: 48,9kN 12 1	Incated with G-rapid + f load: 48,9kN	c. test data (Lubrication, washer type etc)						
15 1 1 16 1 1 16 1 1 17 1 1 18 1 19 1 20 1 21 1 22 1 23 1 24 1 25 1 26 1 27 1 28 1 29 1 30 1 1.75 D0 17,75 17,25 10,863 13,2 Oit data 1	15 16 a 15 a 16 nsion M12 Length 18 gth 8 gth 19 20 11 21 11 22 11 23 11 24 11 25 11 26 11 27 11 28 11 29 11 30 11	ubricated with G-rapid +	_					
ion M12 Length 17 18 ion M12 Length 19 10 h 8 19 10 ion FZV 21 10 WAP: 18mm 24 10 ion 17,25 10,863 ion 13,2 ott data Statistics	a 17 1 1 a 19 1 1 nsion M12 Length 1 gth 8 19 1 gth 8 12 1 insion FZV 22 1 WAP: 18mm 26 1 1 P) 17.75 D0 17.25 10,863 dh 13,2 bolt data Statistics	TOOT IOAd: 48,9KN						
don M12 Length - h 8 - - eat. FZV - - WAP: 18mm 22 - - 0 17.5 D0 17.25 - 10,863 dh 13.2 - - Statistics - - - - Average μ 0,11 - - -	a 18 1 1 nsion M12 Length 19 1 1 gth 8 21 1 1 1 gth 8 22 1 1 1 1 wAP: 18mm 26 1 1 1 1 1 p) 1.75 D0 17.25 26 1							
ion M12 Length - h 8 - 20 - 20 21 - - 21 22 - - 23 24 - - 24 25 - - 25 26 - - 26 29 - - 28 - - - 29 - - - oit data - - - Statistics	a 19 10 10 ston M12 Length 12 12 gth 8 12 12 12 freat. FZV 12 12 12 WAP: 18mm 26 12 12 12 24 10 12 12 12 bolt data 13,2 30 13 13 Statistics Average μ 0,11	[]	_					
ion M12 Length	nsion M12 Length							
Alon M12 Length	nsion M12 Length - 21							
h 8 eat. FZV WAP: 18mm) 1.75 D0 17.25 10.863 dh 13.2 Statistics - Average μ 0.11	gth 8 rreat. FZV WAP: 18mm P) 17.75 10.863 dh 13.2 Statistics Average μ 0.11	nsion M12 Length -						
23 24 eat. FZV WAP: 18mm 25 1.75 D0 17.75 D0 10,863 dh 13,2 0t data Statistics Average μ D,11	gal 23 1 ineat. FZV 24 1 WAP: 18mm 25 1 1 26 27 28 1 27 28 1 1 29 1 1 1 bolt data Statistics 1							
wAP: 18mm 25 10,863 11,25 10,863 0h 13,2 olt data Statistics	WAP: 18mm 25 10,863 13,2 P) 17,75 D0 17,25 10,863 dh 13,2 bolt data Statistics	igth ⁸						
WAP: 18mm 26 100 1.75 D0 17,25 28 10,863 dh 13,2 0it data	WAP: 18mm 26 10,863 17,25 10,863 0h 13,2 10,863 10,11 bolt data Statistics 0,11 11	Treat. FZV						
1.75 D0 17,25 10,863 dh 13,2 0 tt data	P) 17.25 10.863 dh 13.2 bolt data							
29 29 20 29 20 20 29 20 20 20 20 20 20 20 20 20 20 20 20 20	29 30 29 30 29 30 29 30 30 29 30 30 30 30 30 30 30 30 30 30 30 30 30							
10,863 dh 13,2 30	10,863 dh 13,2 oit data Statistics Average μ 0,11) 1,75 D0 17,25						
Average µ 0,11	Average µ 0,11	10.863 db 13.2	_					
Average µ 0,11	Average µ 0,11		. 30					
Average µ 0,11	Average µ 0,11	bolt data						
		r	 Statistics 	5				
Standard deviation µ 0,01	Standard deviation µ 0.01			Average (μ	0,	11	
Standard deviation µ	Standard deviation µ							
				Standard	deviation µ	0,0	10	
				Standard	deviation µ	0,	01	



A5.12 FZV, Molykote 1000

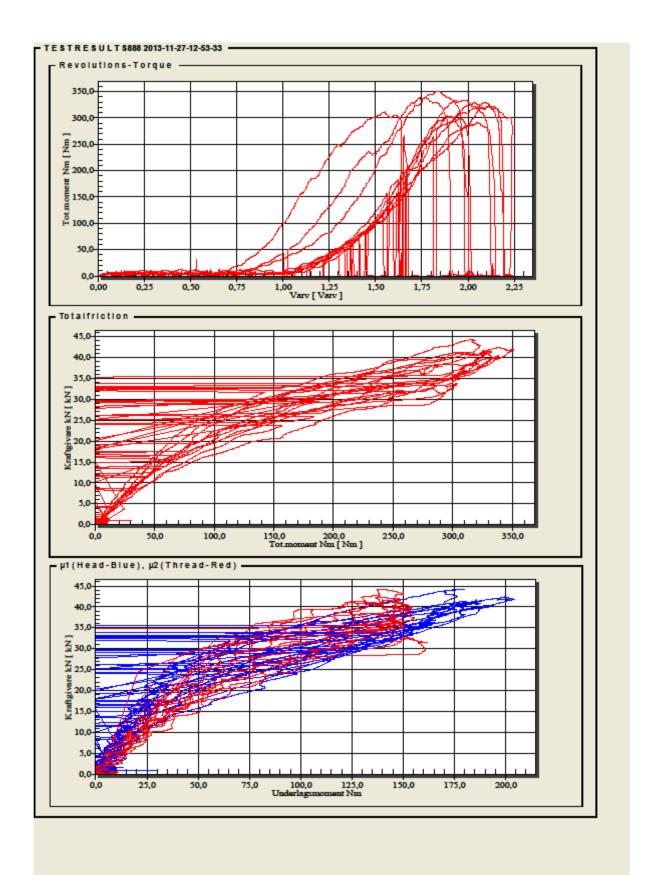
Customer		Fmax [kN]	Tmax (Nm)	µ total	µ1	μ2
Bachelor - frictiontest	1	54,0	102,8	0,12	0,15	0,08
	2	54,0	118,6	0,13	0,15	0,11
	3	52,7 52,5	104,3 95,5	0,13	0,15	0,11
	5	51,5	95,5	0,12	0,14	0,10
st data	6	56,3	98,6	0,11	0,13	0,10
	7	51,1	98,1	0,12	0,15	0,10
est type: Separate Head and Thread friction	8					
	9					
leasure RPM 10	10					
	11					
lisc. test data (Lubrication, washer type etc)	13					
Lubricated with Molykote 100. Proof load: 48,9kN	14					
Plool load. 40,9kN	15					
	16					
	17					
	18					
t data	19					
	20 21					
Nimension M12 Length -	21					
trength ⁸	23					
	24					
urf.Treat. FZV	25					
lead WAP: 18mm	26					
4.75	27					
Itch(P) 1.75 D0 17,25	28					
2 10,863 dh 13,2	29					
	. 30					
lisc. bolt data						
	- Statistic	5				
		Average (0,	12	
		/ recorded a	-			
		Standard	deviation µ	0,	01	



A5.13 A4-80, no lubrication

- TESTRESULTS 2013-11-27-12-53-33

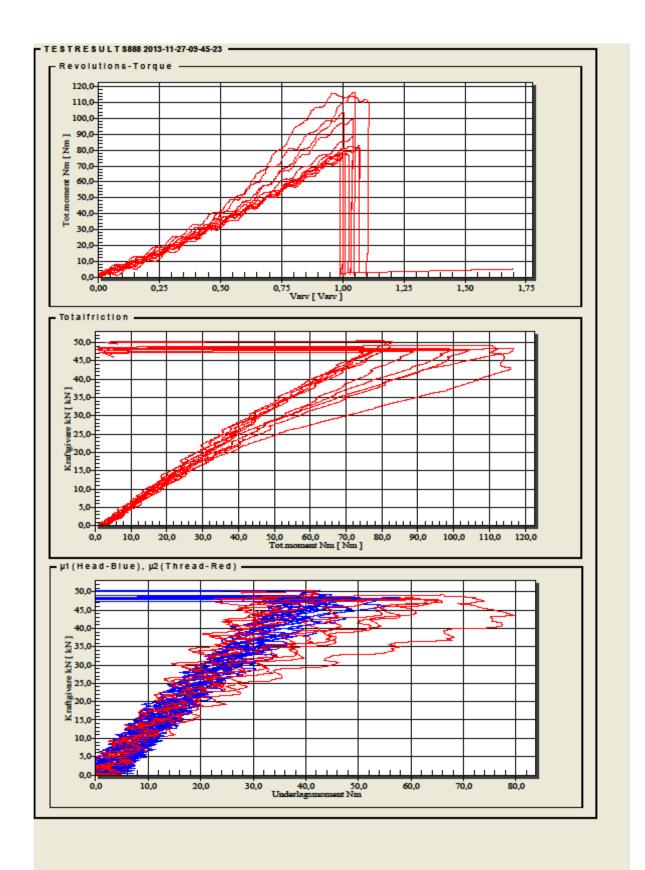
Dasheles, Edulation			Tmax (Nm)	µ total	μt	μ2
Bachelor - Frictiontest	1	33,9		0,48	0,44	0,54
	2	32,6 41,7	294,0 329,2	0,40	0,35	0,46
	3	41,7	329,2	0,44	0,54	0,31
	5	38,1	291,4	0,30	0,26	0,34
ata	6	44,3	323,0	0,43	0,33	0,57
	7	40,4	338,5	0,50	0,46	0,57
type: Separate Head and Thread friction	8	36,9	311,3	0,57	0,54	0,61
type. Separate fread and fillead incool	9	39,7	321,7	0,43	0,40	0,46
sure RPM 10	10 11	42,4	351,1	0,36	0,33	0,39
test data (Lubrication, washer type etc)	12					
thout lubrication	13					
of load: 46kN	14					
	15					
	16					_
	17					
h-	18					_
ta	19					
	20					
ension M12 Length -	21					
ngth 80	22					
	23 24					
Treat. Austenitic steel A4	24					
	26					
WAP: 19mm	27					
P) 1.75 D0 18	28					
	29					
10,863 dh 13,2	30					
bolt data						
	- Statistics					
		Average (42	
		Standard	deviation µ	0,	08	
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A5.14 A4-80, G-rapid +

TESTRESULTS 2013-11-27-09-45-23 -----

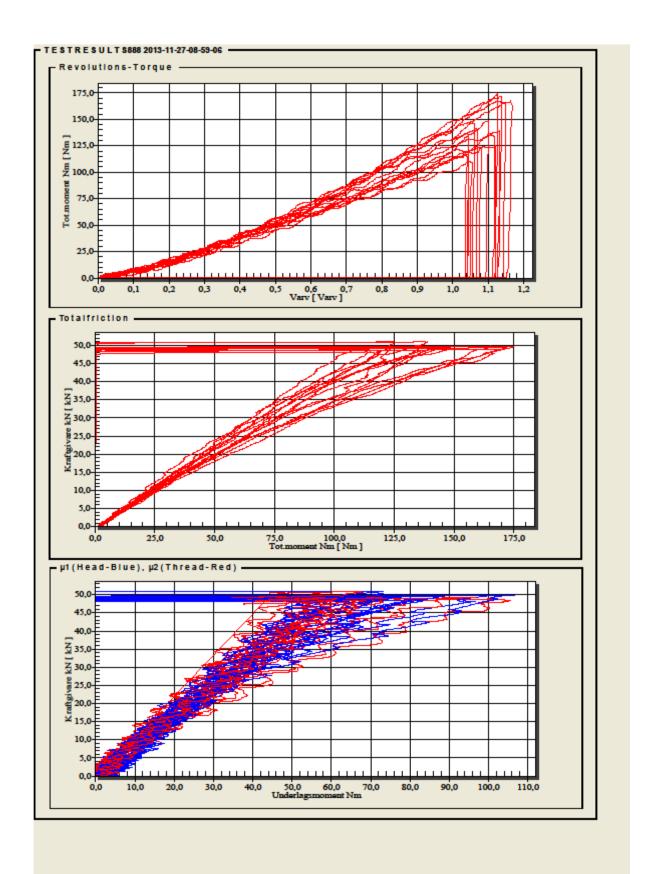
104,5 116,0 81,4 99,2 75,1 77,8 116,7 78,6 81,5 82,9 88,7	0,17 0,09 0,11 0,09 0,09 0,12 0,09 0,09 0,09	0,10 0,11 0,09 0,08 0,09 0,11 0,12 0,10 0,12 0,10	0,16 0,24 0,09 0,15 0,09 0,07 0,13 0,07 0,06 0,06 0,13
81,4 99,2 75,1 77,8 116,7 78,6 81,5 82,9	0,09 0,11 0,09 0,09 0,12 0,09 0,09 0,09 0,10	0,09 0,08 0,09 0,11 0,12 0,10 0,12 0,12	0,09 0,15 0,09 0,07 0,13 0,07 0,06 0,06
99,2 75,1 77,8 116,7 78,6 81,5 82,9	0,11 0,09 0,09 0,12 0,09 0,09 0,09 0,10	0,08 0,09 0,11 0,12 0,10 0,12 0,12	0,15 0,09 0,07 0,13 0,07 0,06 0,06
75,1 77,8 116,7 78,6 81,5 82,9	0,09 0,09 0,12 0,09 0,09 0,10	0,09 0,11 0,12 0,10 0,12 0,12	0,09 0,07 0,13 0,07 0,06 0,06
77,8 116,7 78,6 81,5 82,9	0,09 0,12 0,09 0,09 0,10	0,11 0,12 0,10 0,12 0,12	0,07 0,13 0,07 0,06 0,06
116,7 78,6 81,5 82,9	0,12 0,09 0,09 0,10	0,12 0,10 0,12 0,12	0,13 0,07 0,06 0,06
78,6 81,5 82,9	0,09 0,09 0,10	0,10 0,12 0,12	0,07 0,06 0,06
81,5 82,9	0,09	0,12	0,06
82,9	0,10	0,12	0,06
leviation µ	0	,02	



A5.15 A4-80, Molykote 1000

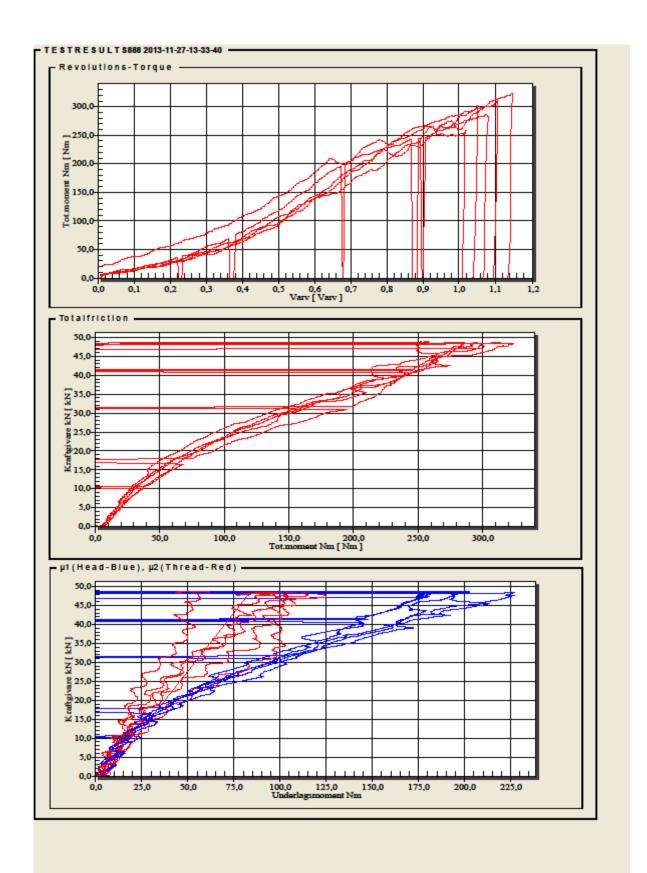
TESTRESULTS 2013-11-27-08-59-06 -----

Customer		Fmax [kN]		µ total	μt	μ2
Bachelor - frictiontest	1	49,0		0,21	0,16	0,27
	2	49,8		0,19	0,21	0,17
	3	48,8	115,9	0,15	0,16	0,13
	4	51,0	125,2	0,16	0,19	0,12
Test data	5	51,0	139,0	0,16	0,14	0,17
rest data	6	49,3	171,9	0,18	0,18	0,18
	7	49,6	135,5	0,19	0,14	0,24
Test type: Separate Head and Thread friction	8	49,7	146,6	0,15	0,16	0,14
	9	49,3	148,7	0,16	0,15	0,16
Measure RPM 10	10	49,1	140,9	0,18	0,20	0,16
	11	48,2	116,9	0,15	0,15	0,15
Misc. test data (Lubrication, washer type etc)	12	49,6	110,2	0,13	0,15	0,11
	13	49,9	165,4	0,20	0,22	0,17
Lubricated with Molykote 1000 Proof load: 46kN	14	48,6	136,2	0,16	0,18	0,13
Ploor load, 40kN	15	49,2	122,4	0,14	0,14	0,14
	16					
	17					
	18					
Bolt data	19					
	20					
Dimension M12 Length	20					
Dimension M12 Length -	21					
Strength ⁸⁰						
ouengan	23					
Surf.Treat. Austenitic steel A4	24					
	25					
Head WAP: 19mm	26					
Ditch/D) 1,75 pp 18	27					
Pitch(P) 1,75 D0 10	28					
d2 10,863 dh 13,2	29					
d2 10,863 dh 13,2	. 30					
Misc. bolt data						
		Standard	deviation µ	0,	02	



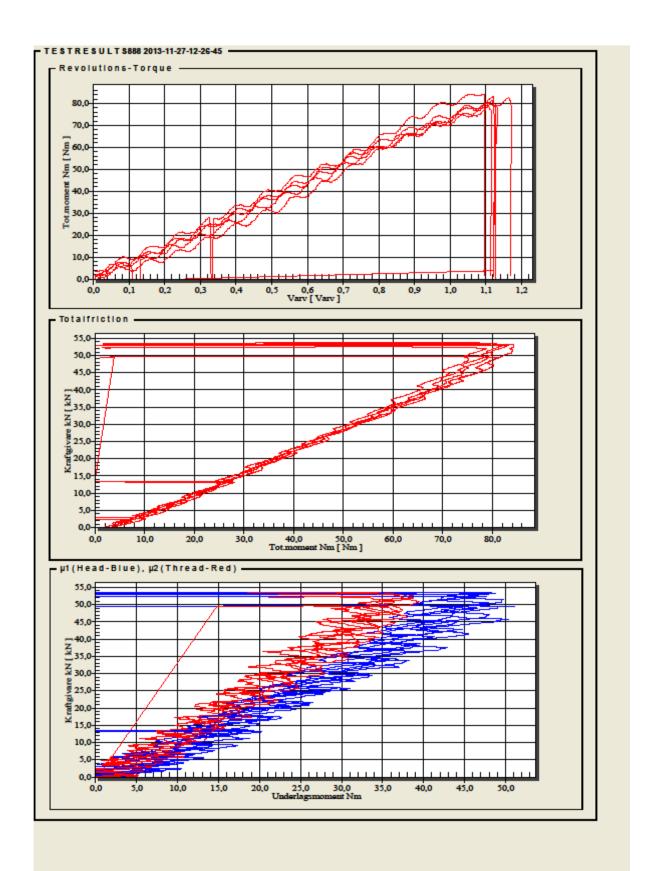
A5.16 A4-80, Gleitmo 605

achelor - Frictionstest 1 44,7 286,8 0,42 0,43 0,33 data	1 1 1 1 1 1 1 1 1 1 1 1 1 10	1 1 1 1 1 1 1 1 1 1 1 1 1 10	1 10 10 10 10 10 10 10 10 10 10 11 1 1 1 1 1 10 12 10 10 11 1 1 1 10 12 10 10 11 1 1 1 10 11 1 10 11 1 10 11 1 1 10 11 1 10 11 1 10 11 1 10	1 10 10 10 10 10 10 10 10 10 10 11 1 1 1 1 1 10 12 10 10 11 1 1 1 10 12 10 10 11 1 1 1 10 11 1 10 11 1 10 11 1 1 10 11 1 10 11 1 10 11 1 10	Bachelor - Frictionstest		Fmax [kN]	Tmax (Nm)	µ total	μt	μ2
3 48,8 313,9 0,38 0,47 0,27 data	3 48,8 313,9 0,38 0,47 0,27 4 48,9 265,1 0,37 0,52 0,17 5 48,5 324,0 0,36 0,46 0,24 6 7 9 0 0 0 0 7 9 0 0 0 0 0 8 9 0 0 0 0 0 0 9 0 0 0 0 0 0 0 0 9 0 <t< th=""><th>3 48,8 313,9 0,38 0,47 0,27 4 48,9 265,1 0,37 0,52 0,17 5 48,5 324,0 0,36 0,46 0,24 6 7 9 0 0 0 0 7 9 0 0 0 0 0 8 9 0 0 0 0 0 0 9 0 0 0 0 0 0 0 0 9 0 <t< th=""><th>3 48,8 313,9 0,38 0,47 0,27 4 48,9 265,1 0,37 0,52 0,17 5 48,5 324,0 0,36 0,46 0,24 6 7 9 0 0 0 0 7 9 0 0 0 0 0 8 9 0 0 0 0 0 0 9 0 0 0 0 0 0 0 0 9 0 <t< th=""><th>3 48,8 313,9 0,38 0,47 0,27 4 48,9 265,1 0,37 0,52 0,17 5 48,5 324,0 0,36 0,46 0,24 6 7 9 0 0 0 0 7 9 0 0 0 0 0 8 9 0 0 0 0 0 0 9 0 0 0 0 0 0 0 0 9 0 <t< th=""><th></th><th></th><th>48,7</th><th>286,5</th><th>0,42</th><th>0,45</th><th>0,38</th></t<></th></t<></th></t<></th></t<>	3 48,8 313,9 0,38 0,47 0,27 4 48,9 265,1 0,37 0,52 0,17 5 48,5 324,0 0,36 0,46 0,24 6 7 9 0 0 0 0 7 9 0 0 0 0 0 8 9 0 0 0 0 0 0 9 0 0 0 0 0 0 0 0 9 0 <t< th=""><th>3 48,8 313,9 0,38 0,47 0,27 4 48,9 265,1 0,37 0,52 0,17 5 48,5 324,0 0,36 0,46 0,24 6 7 9 0 0 0 0 7 9 0 0 0 0 0 8 9 0 0 0 0 0 0 9 0 0 0 0 0 0 0 0 9 0 <t< th=""><th>3 48,8 313,9 0,38 0,47 0,27 4 48,9 265,1 0,37 0,52 0,17 5 48,5 324,0 0,36 0,46 0,24 6 7 9 0 0 0 0 7 9 0 0 0 0 0 8 9 0 0 0 0 0 0 9 0 0 0 0 0 0 0 0 9 0 <t< th=""><th></th><th></th><th>48,7</th><th>286,5</th><th>0,42</th><th>0,45</th><th>0,38</th></t<></th></t<></th></t<>	3 48,8 313,9 0,38 0,47 0,27 4 48,9 265,1 0,37 0,52 0,17 5 48,5 324,0 0,36 0,46 0,24 6 7 9 0 0 0 0 7 9 0 0 0 0 0 8 9 0 0 0 0 0 0 9 0 0 0 0 0 0 0 0 9 0 <t< th=""><th>3 48,8 313,9 0,38 0,47 0,27 4 48,9 265,1 0,37 0,52 0,17 5 48,5 324,0 0,36 0,46 0,24 6 7 9 0 0 0 0 7 9 0 0 0 0 0 8 9 0 0 0 0 0 0 9 0 0 0 0 0 0 0 0 9 0 <t< th=""><th></th><th></th><th>48,7</th><th>286,5</th><th>0,42</th><th>0,45</th><th>0,38</th></t<></th></t<>	3 48,8 313,9 0,38 0,47 0,27 4 48,9 265,1 0,37 0,52 0,17 5 48,5 324,0 0,36 0,46 0,24 6 7 9 0 0 0 0 7 9 0 0 0 0 0 8 9 0 0 0 0 0 0 9 0 0 0 0 0 0 0 0 9 0 <t< th=""><th></th><th></th><th>48,7</th><th>286,5</th><th>0,42</th><th>0,45</th><th>0,38</th></t<>			48,7	286,5	0,42	0,45	0,38
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13 13 14 ubricated with Gieltmo 605 1:5 14 15 14 15 14 15 16 17 16 17 18 17 18 11 18 19 11 20 11 11 21 11 11 22 11 11 23 11 11 24 11 11 25 11 11 26 11 11 27 11 11 28 11 11 29 11 11 30 11 12 Statistics	13 13 14 13 14 15 14 15 16 15 16 17 16 17 18 17 18 19 20 21 14 20 21 14 22 14 16 18 19 10 21 14 16 22 16 17 23 16 17 24 16 17 23 16 17 24 16 17 25 16 17 26 27 17 28 16 17 29 10.863 13.2 30 13.2 16 17 30 13.2 16 17 30 17 17 17 30 13.2 16 17 30 13.2 16 17 30 17 17 17	13 13 14 13 14 15 14 15 16 15 16 17 16 17 18 17 18 19 20 21 14 20 21 14 22 14 16 18 19 10 21 14 16 22 16 17 23 16 17 24 16 17 23 16 17 24 16 17 25 16 17 26 27 17 28 16 17 29 10.863 13.2 30 13.2 16 17 30 13.2 16 17 30 17 17 17 30 13.2 16 17 30 13.2 16 17 30 17 17 17	13 13 14 13 14 15 14 15 16 15 16 17 16 17 18 17 18 19 20 21 11 22 11 11 23 11 11 24 11 11 25 11 11 26 11 11 27 11 11 28 11 11 29 11 11 30 11 11 Statistics	13 13 14 13 14 15 14 15 16 15 16 17 16 17 18 17 18 19 20 21 11 22 11 11 23 11 11 24 11 11 25 11 11 26 11 11 27 11 11 28 11 11 29 11 11 30 11 11 Statistics							
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Austenitic steel A4 23 24 ad WAP: 19mm 25 26 26 27 28 27 28 29 10,863 dh 13.2 c. bolt data Statistics	Austentitic steel A4 23 24 ad WAP: 19mm 26 ad WAP: 19mm sh(P) 1.75 D0 10,863 dh 13,2 30 c. bolt data	Austentitic steel A4 23 24 ad WAP: 19mm 26 ad WAP: 19mm sh(P) 1.75 D0 10,863 dh 13,2 30 c. bolt data	Austentitic steel A4 23 24 ad WAP: 19mm 26 ad WAP: 19mm sh(P) 1.75 D0 10,863 dh 13,2 30 c. bolt data	Austentitic steel A4 23 24 ad WAP: 19mm 26 ad WAP: 19mm sh(P) 1.75 D0 10,863 dh 13,2 30 c. bolt data							
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d WAP: 19mm h(P) 1.75 D0 18 10,863 dh 13,2 bott data Statistics Average µ 0,38	d WAP: 19mm h(P) 1.75 D0 18 10,863 dh 13,2 29 30 10 10 10 10 10 10 10 10 10 10 10 10 10	d WAP: 19mm h(P) 1.75 D0 18 10,863 dh 13,2 29 30 10 10 10 10 10 10 10 10 10 10 10 10 10	d WAP: 19mm h(P) 1.75 D0 18 10,863 dh 13,2 bott data Statistics Average μ 0,38 27 28 29 30 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4	d WAP: 19mm h(P) 1.75 D0 18 10,863 dh 13,2 bott data Statistics Average μ 0,38 27 28 29 30 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4	Treat. Austenitic steel A4						
1,75 D0 18 10,863 dh 13,2 . bolt data	1,75 D0 18 10,863 dh 13,2 . bolt data	1,75 D0 18 10,863 dh 13,2 . bolt data	1,75 D0 18 10,863 dh 13,2 . bolt data	1,75 D0 18 10,863 dh 13,2 . bolt data	WAP: 19mm						
10,863 dh 13,2 bolt data Statistics Average μ 0,38	10,863 dh 13,2 29	10,863 dh 13,2 29	10,863 dh 13.2 29	10,863 dh 13.2 29							
10,863 dh 13,2 . 30	10,863 dh 13,2 boit data	10,863 dh 13,2 boit data	10,863 dh 13,2 boit data Statistics Average μ 0,38	10,863 dh 13,2 boit data Statistics Average μ 0,38	(P) 1,75 D0 18						
bolt data	bolt data Statistics Average µ 0,38	bolt data Statistics Average µ 0,38	bolt data Statistics Average µ 0,38	bolt data Statistics Average µ 0,38	10,863 db 13,2						
Average µ 0,38	Average µ 0,38	Average µ 0,38	Average µ 0,38	Average µ 0,38		. 30					
Average µ 0,38	Average µ 0.38	Average µ 0.38	Average µ 0.38	Average µ 0.38	bolt data						
										20	
Standard deviation µ 0,02	Standard deviation µ 0.02	Standard deviation μ 0.02	Standard deviation μ 0.02	Standard deviation μ 0,02			Average	μ	u,	30	
							Standard	deviation µ	0,	02	



A5.17 Zinc Flake, no lubrication

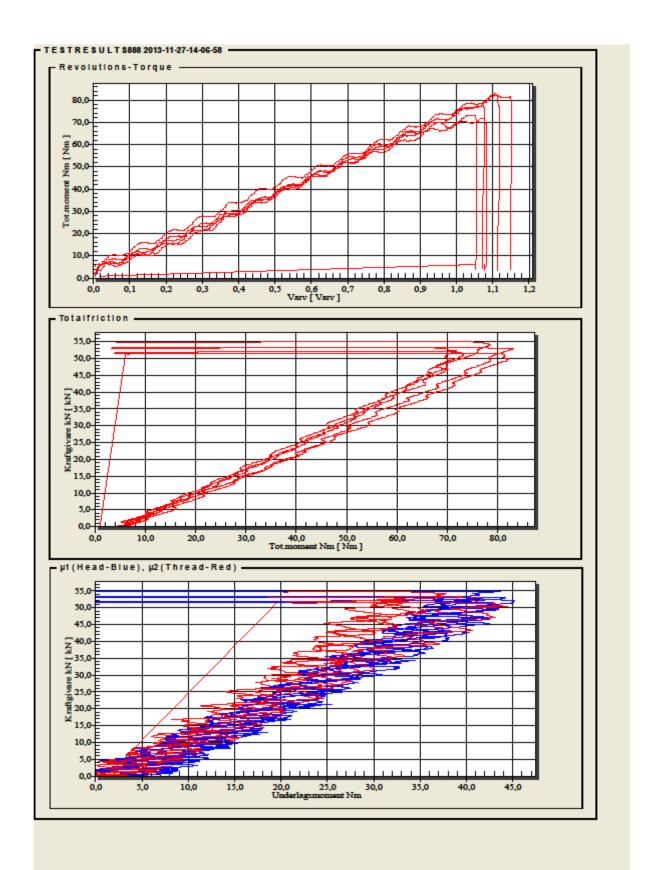
achelor - Frictiontest 1 data 1 data 6 at type: Separate Head and Thread friction 8 assure RPM 10 10 11 2. test data (Lubrication, washer type etc) 13 thout lubrication 16 11 17 ata 19 ata 19 ata 19 ength 8 1.Treat. Zinc Flake ad WAP: 18mm c. bolt data 13.2 c. bolt data Statistics	Average	82,5 84,3 78,9 83,3 83,3 83,3 83,3 83,3 83,3 83,3 8	0 0,12	2 0,08 1 0,09 3 0,07
3 data data st type: Separate Head and Thread friction assure RPM 10 10 10 11 12 13 14 15 16 17 18 19 20 13 14 15 16 17 18 19 20 11 21 22 18 19 20 21 22 23 1.Treat. ZIn Flake 24 25 26 27 10,863 13,2 20 30	53,4 52,5 53,2	μ	0,10	1 0,09 3 0,07
4 data data st type: Separate Head and Thread friction asure RPM 10 asure RPM 10 11 12 thout lubrication, washer type etc) thout lubrication more load: 48,9kN 15 16 17 ata ension M12 Length 8 17 ad WAP: 18mm th(P) 1,75 10 13,2 20 17 28 29 .	52,5 53,2 Average	μ	0,10	3 0,07
data 5 at type: Separate Head and Thread friction 8 asure RPM 10 asure RPM 10 10 11 12 11 13 12 14 15 15 16 16 17 18 19 ength 8 17 18 ad WAP: 18mm th(P) 1,75 10,863 13,2 c. bolt data .	53,2	μ	0,10	
data 6 ast type: Separate Head and Thread friction 8 assure RPM 10 10 11 assure RPM 10 11 12 12 11 13 12 14 15 15 16 16 17 18 16 17 18 asta 19 ad M12 Length 21 22 23 f. Treat. Zinc Flake 26 24 27 28 29 30 c. bolt data 13.2	Average	h	0,10	
asure RPM 10 10 asure RPM 10 11 asure RPM 10 11 asure RPM 10 11 asure RPM 10 11 aster data (Lubrication, washer type etc) 13 13 tithout lubrication 14 15 ata 19 16 17 ata 19 20 16 nension M12 Length 21 22 and WAP: 18mm 24 25 24 25 ad WAP: 18mm 26 27 28 29 30 30 c. bolt data 13.2 	Average	-		
9 asure RPM 10 10 11 11 12 11 12 11 12 11 13 12 13 13 14 15 16 16 17 18 19 19 20 11 22 11 22 11 13 12 13 13 14 14 15 15 16 17 18 18 20 19 20 20 21 21 22 23 24 25 23 24 25 25 24 26 27 28 29 30 0 10,863 13,2 30 0	Average	-		
assure RPM 10 10 assure RPM 10 11 assure RPM 10 11 beta at a 13 13 tithout lubrication roof load: 48,9kN 15 16 ata 19 16 17 ata 19 20 21 tension M12 Length 21 ad WAP: 18mm 24 25 ad WAP: 18mm 26 28 ach(P) 1,75 D0 17,25 28 29 .0 .0 .0 .0 c. bolt data	Average	-		
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2. test data (Lubrication, washer type etc) 12 13 13 14 15 16 17 18 16 17 18 18 19 20 21 21 22 ength 8 17. Treat. Zinc Flake 23 24 25 26 26 27 28 29 10,863 13,2 c. bolt data	Average	-		
i. test data [Lubrication, washer type etc] 13 13 14 14 15 15 16 16 17 18 18 19 20 20 21 18 19 20 21 18 23 11. Treat. Zinc Flake 23 24 25 26 26 27 27 28 29 10,863 13.2 20	Average	-		
ada M12 Length 14 intension M12 Length 16 intension M12 Length 20 ada WAP: 18mm 23 ad WAP: 18mm 26 ah(P) 1,75 D0 17,25 10,863 dh 13,2 c. bolt data	Average	-		
15 ata nension M12 Length 18 19 20 21 22 angth 8 1.Treat. Zinc Flake 24 25 26 27 10,863 13,2 20	Average	-		
ata 17 hension M12 Length 19 20 ength 8 1. Treat. Zinc Flake ad WAP: 18mm ah(P) 1,75 10,863 dh 13,2 c. bolt data	Average	-		
ata 18 nension M12 Length 19 ength 6 21 ength 6 23 ft.Treat. Zinc Flake 24 ad WAP: 18mm 26 ah(P) 1,75 D0 17,25 10,863 dh 13,2 c. bolt data	Average	-		
ata 19 hension M12 Length ength 8 1.Treat. Zinc Flake ad WAP: 18mm wAP: 18mm 26 27 28 10,863 13,2 c. bolt data	Average	-		
mension M12 Length 20 ength 8 22 intreat. Zinc Flake 23 ad WAP: 18mm 26 intreat. 17.25 29 intreat. 10,863 dh intreat. 13.2 30	Average	-		
angth 8 22 1. Treat. Zinc Flake 23 ad WAP: 18mm 26 ah(P) 1.75 D0 17,25 10,863 dh 13,2 c. bolt data	Average	-		
8 22 1. Treat. Zinc Flake 24 ad WAP: 18mm 26 xh(P) 1.75 D0 17.25 10,863 dh 13.2 30 c. bolt data	Average	-		
1. Treat. Zinc Flake 24 ad WAP: 18mm 26 ad WAP: 18mm 26 ah(P) 1.75 D0 17.25 10,863 dh 13.2 c. bolt data	Average	-		
t. Treat. 2110 Flake 25 ad WAP: 18mm 26 ah(P) 1.75 D0 17.25 10.863 dh 13.2 c. bolt data	Average	-		
ad WAP: 18mm 26 27 28 29 10,863 dh 13,2 30 c. bolt data	Average	-		
h(P) 1.75 D0 17.25 28 29 10.863 dh 13.2 30 c. bolt data	Average	-		
10,863 dh 13,2 29 . 30 c. boit data	Average	-		
10,863 dh 13,2 29 c. bolt data	Average	-		
c. bolt data	Average	-		
	Average	-		
Statistics	Average	-		
	_	-		
	_	-		
	_	-		
	Standard	deviation µ	0,00	



A5.18 Zinc Flake, G-Rapid +

TESTRESULTS 2013-11-27-14-06-58

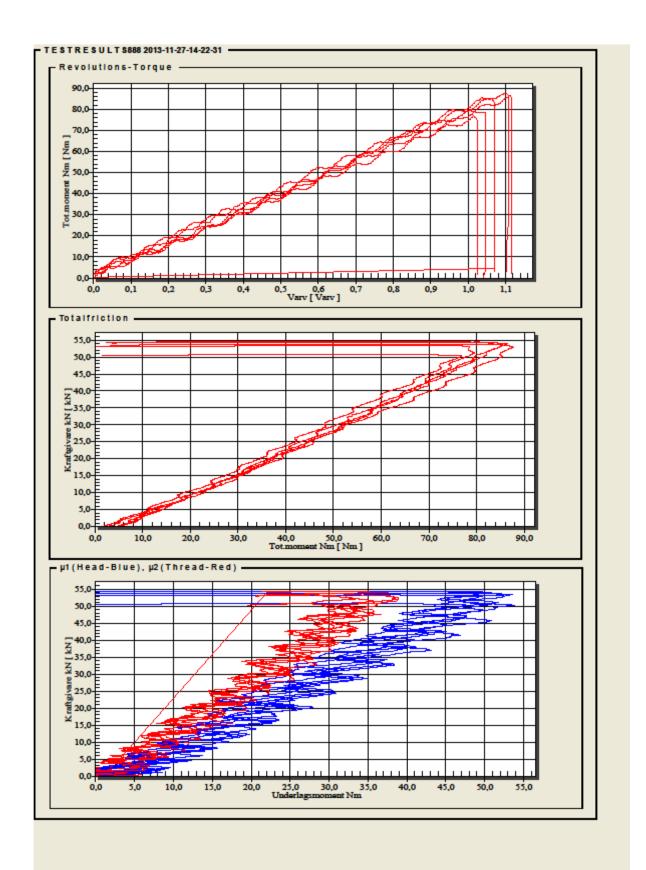
Customer			Tmax (Nm)	µ total	µ1	μ2
Bachelor - frictiontest	1	52,0	73,2	0,09	0,10	0,07
	2	53,3 53,2	83,2 71,9	0,10	0,11 0,12	0,09
	3	55,0	78,5	0,09	0,12	0,05
at data	5	51,6	82,2	0,09	0,11	0,00
st data	6					
	7					
Test type: Separate Head and Thread friction	8					
10	9					
Measure RPM 10	10					
	12					
Also, test data (Lubrication, washer type etc)	13					
Lubricated with G-Rapid + Proof load: 48,9kN	14					
	15					
	16					
	18					
t data	19					
	20					
Dimension M12 Length -	21					
	22					
Strength 8	23					
Surf.Treat. Zinc Flake	24 25					
	25					
	27					
Pitch(P) 1,75 D0 17,25	28					
10,863 dh 13,2	29					
12 10,863 dh 13,2	. 30					
lisc. bolt data						
	- Statistic					
		Average	u	0,	09	
		Standard	deviation µ	0,	01	
	-					

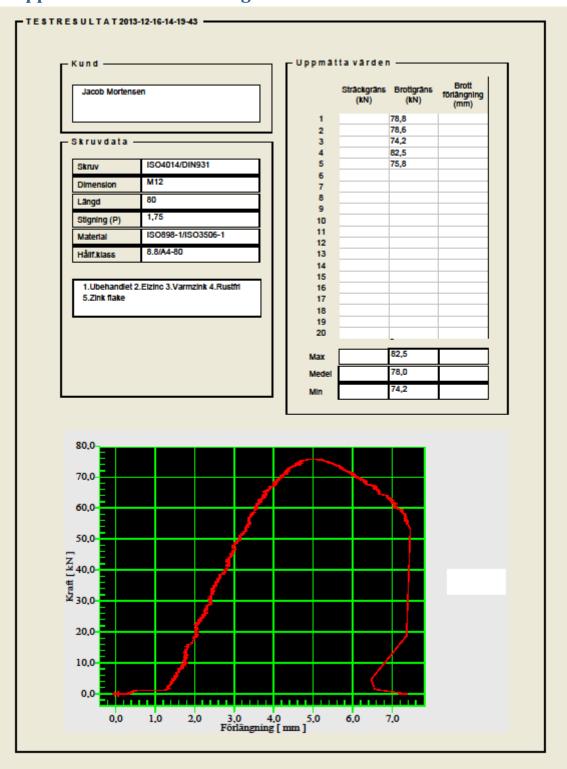


A5.19 Zinc Flake, Molykote 1000

- TESTRESULTS 2013-11-27-14-22-31 ------

Dustomer Finax [kN] Tmax (Nm) µ total µ1 µ2 Bachelor - Frictiontest 1 54,4 85,2 0,10 0,12 0,0 2 54,5 86,6 0,10 0,12 0,0 2 53,3 79,6 0,09 0,13 0,0 4 50,7 76,9 0,09 0,13 0,0 4 50,7 76,9 0,09 0,13 0,0 4 50,7 76,9 0,11 0,14 0,0 6 - - - - - - 7 - <th>06 08 05</th>	06 08 05
3 53,3 79,6 0,10 0,12 0,0 data 5 53,7 76,9 0,09 0,13 0,0 st type: Separate Head and Thread friction 5 53,7 87,8 0,11 0,14 0,0 asure RPM 10 6 10 <th>08 05</th>	08 05
4 50,7 76,9 0,09 0,13 0,0 sta 5 53,7 87,8 0,11 0,14 0,0 type: Separate Head and Thread friction 10 11 10 11 10 11 <	05
5 53,7 87,8 0,11 0,14 0,0 6 7 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 11 10 11 10 11 10 11 10 11 10 11 11 10 11 <t< td=""><td></td></t<>	
6 6 6 6 7 10 10 10 10 10 10 10 11 10 10 10 12 10 11 10 13 10 11 10 14 10 11 10 15 10 11 10 14 10 10 10 15 10 10 10 16 10 10 10 18 10 10 10 19 10 10 10 18 10 10 10 19 10 10 10 11 10 10 10 10 12 10 10 10 10 13 10 10 10 10 10 14 10 10 10 10 10 10 18 10 10 10 10 10 10 10 12	
8 9 9 9 9 9 9 9 9 9 9 9 9 9 9 10 12 10ad: 48,9kN 16 17 18 20 21	
9 0 ure RPM 10 test data (Lubrication, washer type etc) 10 nicated with Molykote 1000 11 of load: 48,9kN 10 a 11 a 11 a 11 a 11 a 11 11 12 12 13 13 14 14 15 15 16 16 11 17 18 18 10 20 12 21 12 22 12 23 14 24 15 25 14 26 14	
10 10 10 11 <td< td=""><td></td></td<>	
11 11 est data (Lubrication, washer type etc) cated with Molykote 1000 load: 48,9kN load: 48,9kN sion M12 Length 11 20 11 20 11 21 12 22 13 23 14 24 14 25 16 26 10	
13 13 14 12 14 15 16 14 15 16 16 16 17 16 17 18 19 11 19 11 11 20 11 11 18 11 11 19 11 11 20 11 11 21 11 11 22 11 11 23 11 11 24 11 11 25 11 11 26 11 11 27 11 11	
13 13 14 14 15 14 15 14 15 16 16 16 17 18 16 18 19 16 19 10 16 20 10 16 21 10 16 22 10 16 23 10 16 24 10 16 25 10 10 26 10 10	
15 1 16 1 17 1 18 1 19 1 20 1 21 1 22 1 23 1 24 1 25 1 26 1	
16	
17	
18 18 19 19 20 19 20 10 21 10 22 10 23 10 24 10 25 10 26 10	
M12 Length - 20 - - - 20 21 22 22 23 - - - - - - 22 23 -	
M12 Length 21	
8 22 23 23 Zinc Flake 24 24 25 WAP: 18mm 26 27 27	
23 23 Zinc Flake 24 25 3 WAP: 18mm 26 27 3	
Zinc Flake 24 24 WAP: 18mm 26 27	_
25 25 26 25 26 26 27 27 26 27 27 26 27 27 26 27 27 26 27 27 26 27 27 26 27 27 26 27 27 26 27 27 26 27 27 26 27 27 26 27 27 26 27 27 26 27 27 26 27 27 26 27 27 26 27 27 27 26 27 27 27 26 27 27 27 27 27 27 27 27 27 27 27 27 27	-
WAP: 18mm 26	-
27	-
	—
.75 D0 17.25 28	
29 29	
0,863 dh 13,2 30	
- Statistics	
Average u 0,10	
Average µ 0,10	
Standard deviation µ 0,01	





A6 Appendix 6 - Tensile strength test