Friction Analysis of Bolts

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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.

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Jacob Mortensen

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.

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

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
12.9/12.9	1200	1080	12

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 8-12μm. 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, MoS_2 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.

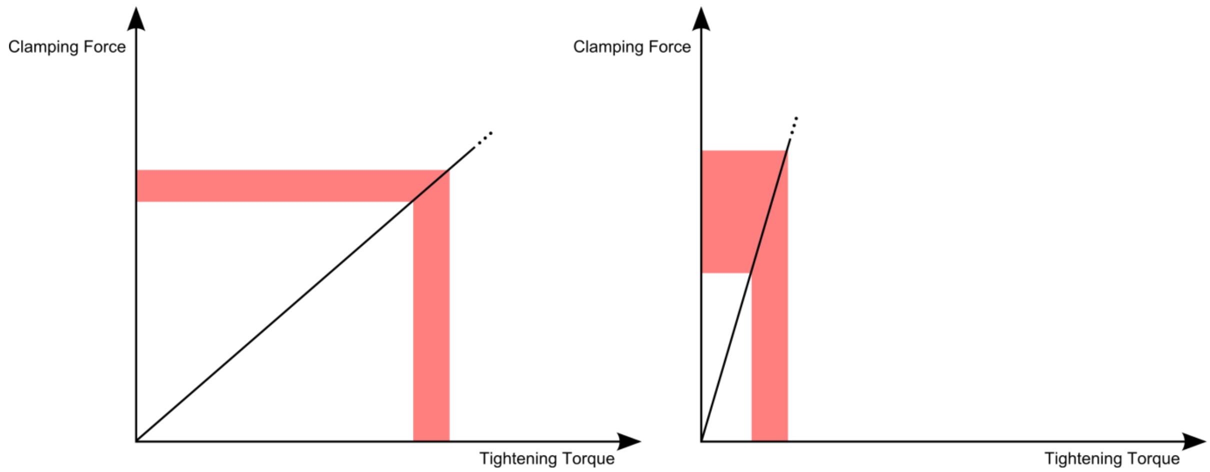


Figure 1. Friction's impact on the achieved clamp force.

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 torsional 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 MoS_2, 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

2.2.4.3 Gleitmo 605

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.

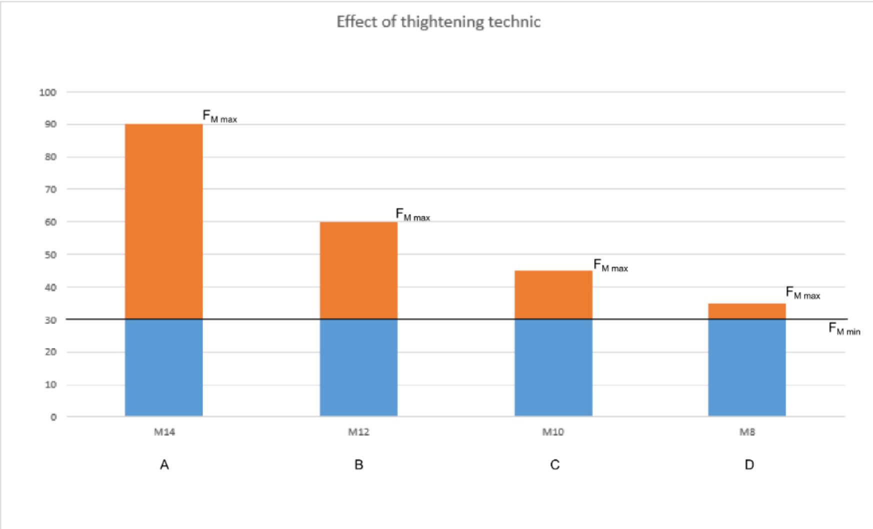


Figure 7. Shows the scatter of preload, when using different tightening method, and the size of 12.9 bolt needed to avoid fracture. A – Impact wrench, B – Bolt installation spindle, C – Torque wrench or precision bolt installation spindle, D – Yield-controlled installation spindle.

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.

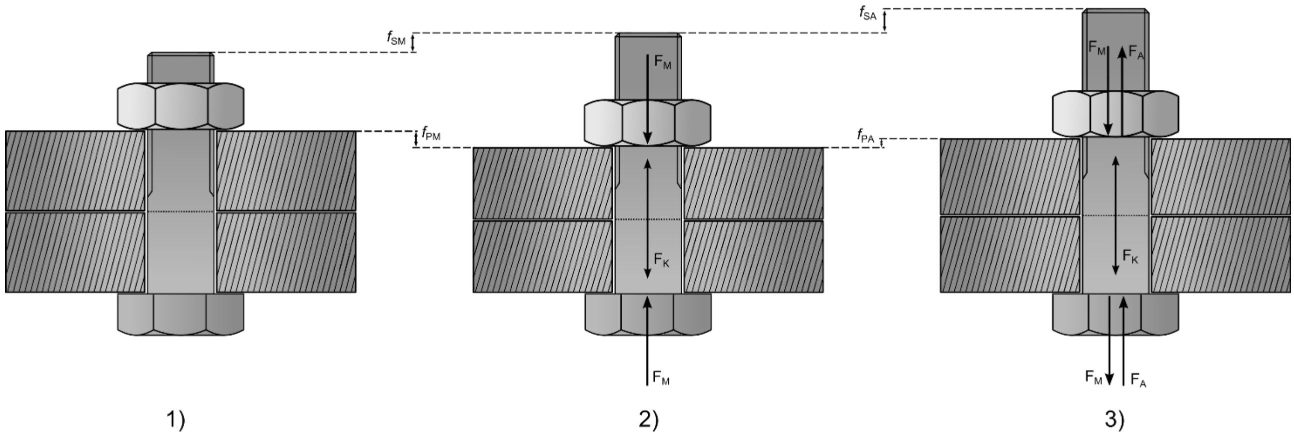


Figure 8. Preloaded bolted joint. 1. Initial state. 2. Assembled state. 3. Working state.

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:

$$F_M - F_K - F_A = 0 \tag{3-2}$$

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.

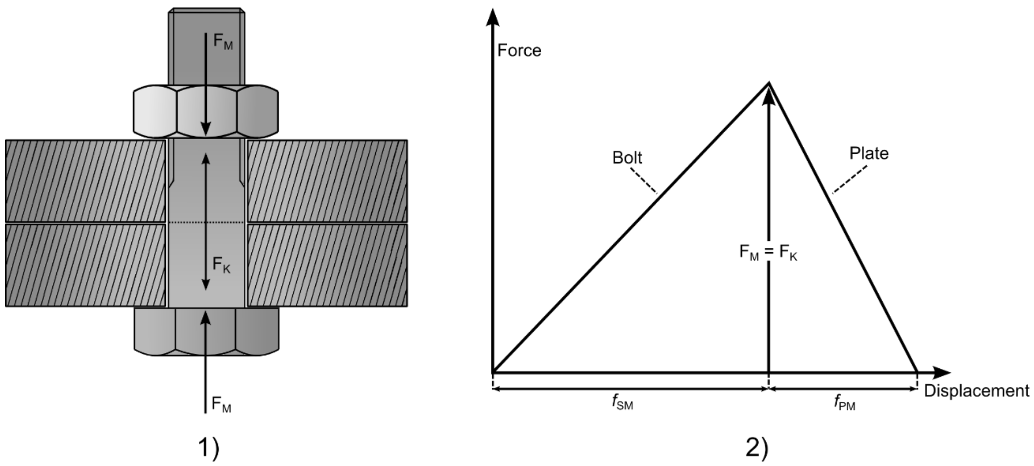


Figure 9. Shows the assembled state of a bolted joint (1), and the corresponding force/displacement diagram (2).

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.

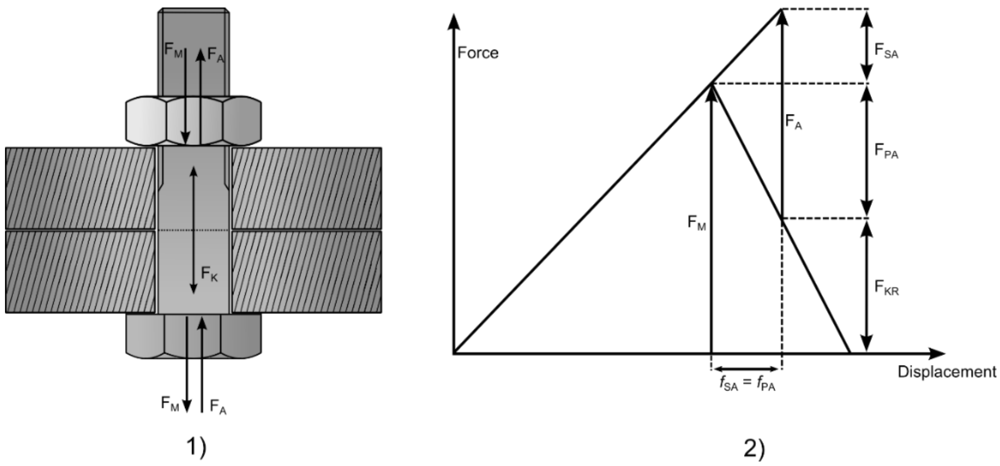


Figure 10. Shows the working state of a bolted joint (1), and the corresponding force/displacement diagram (2).

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.

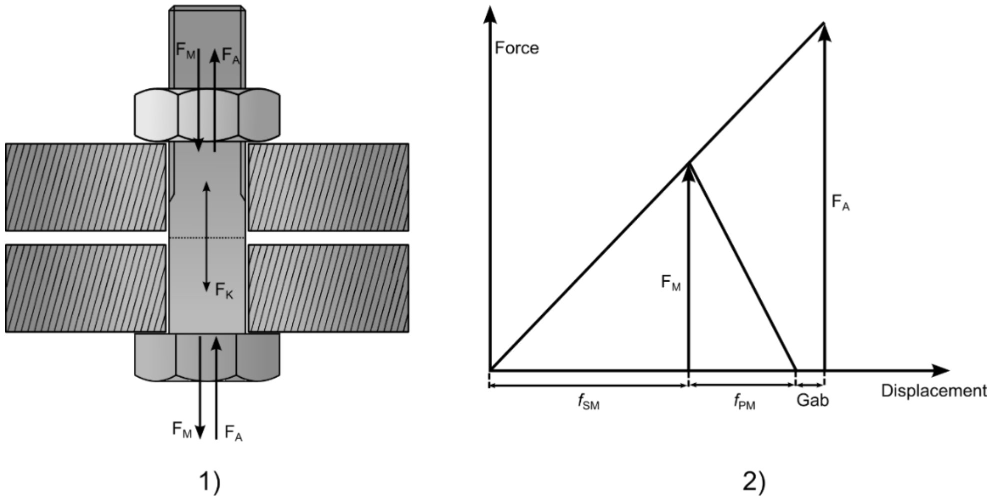


Figure 11. Shows the gap state of a bolted joint (1), and the corresponding force/displacement diagram (2).

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 $M_{ü}$ 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:

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

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

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.

$$\tan(\varphi + \rho') \approx \tan(\varphi) + \tan(\rho') = \frac{P}{(\pi \cdot d_2)} + 1{,}155\mu_G \tag{3-7}$$

Thus:

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

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:

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

Where

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

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:

$$M_K = F_M \cdot \frac{D_{Km}}{2} \cdot \mu_K \qquad (3\text{-}11)$$

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.

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

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.

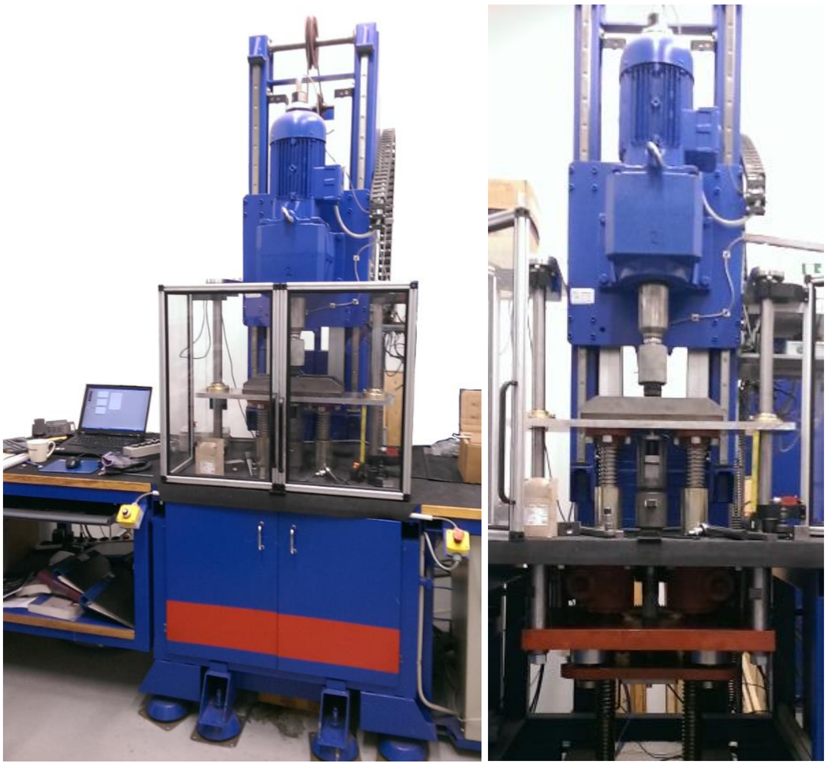


Figure 12. The full test setup. 1. In test state with the safety glass and doors closed. 2. Close-up of the whole setup.

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.

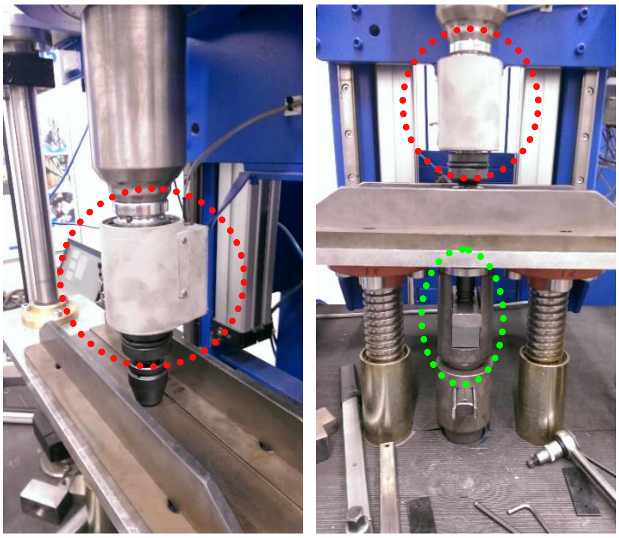


Figure 14. The torque meter are marked with a red circle. A tool to turn the nut is mounted on the torque meter, while the green circle marks the tool to hold the head of the bolt.

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.

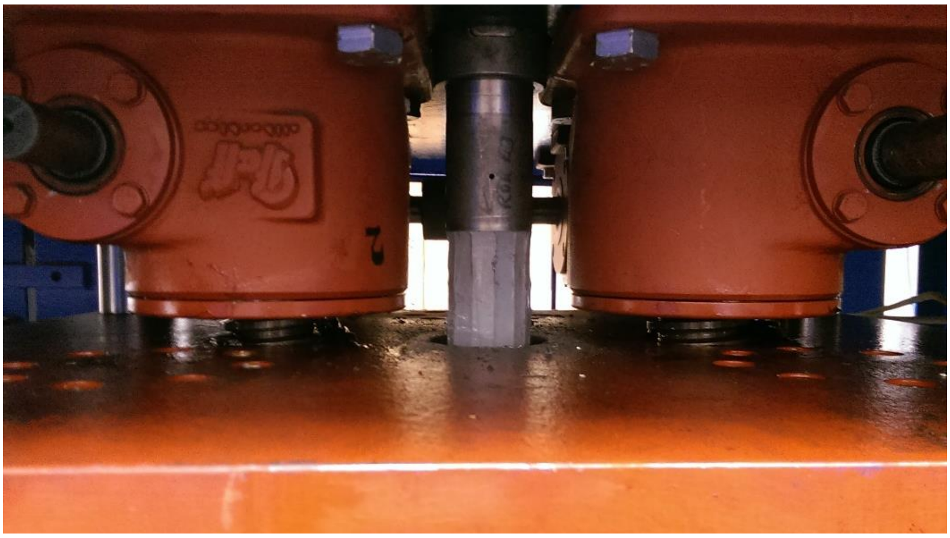


Figure 15. Underneath the table. The shaft in the middle has a torque meter mounted, which is the lighter grey part. The orange parts on the side are motors/gears for changing the height of the test bench.

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.

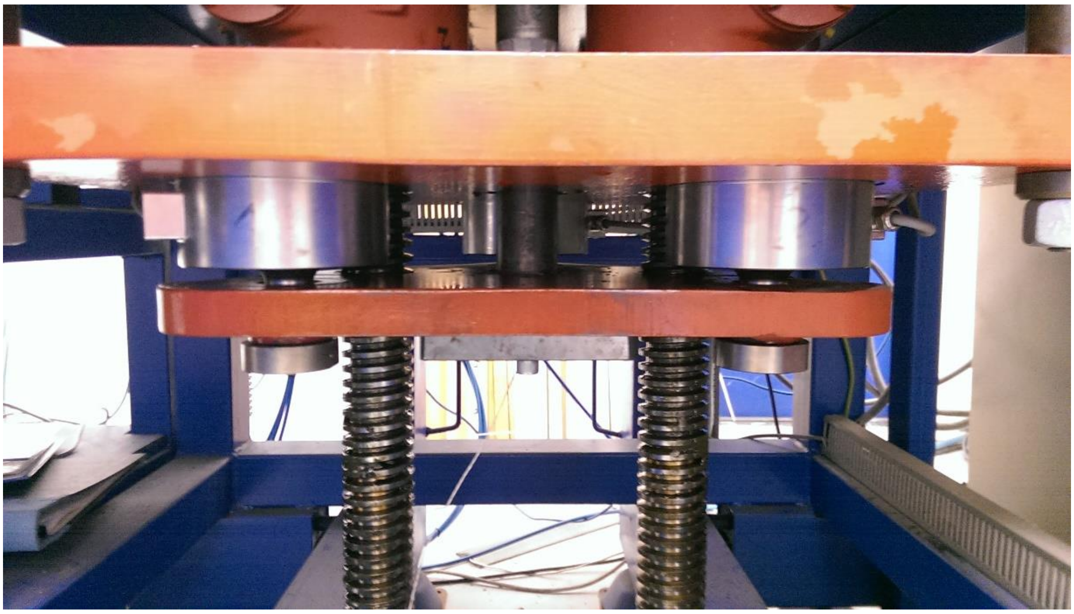


Figure 16. Bottom of the test machine. In the middel are the shaft from the test bench. The three metal cylinders that is placed on the left, right and behind the shaft are the load cells.

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.

Table 6. Shows some of the factors that have influence on the tightening of a bolted joint.

Fastener	Clamped parts	Enviroment	Tool
•Design •Lubricant •Material •Surface treatment •Imperfections •Tolerances	•Surface roughness •Material •Hole size	•Dirt •Water •Corrosion	•Tightening speed •Scatter •Method of tightening •Utilization of strenght

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.

Figure 17. Shows two bolts being tested for thread tolerances with a go/no go test.

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] http://www.fullermetric.com/technical/information/tech_thread_tolerance.aspx (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 ± 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:

1. 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.

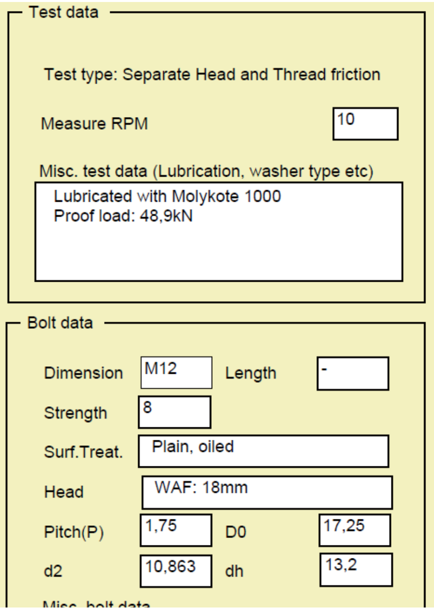
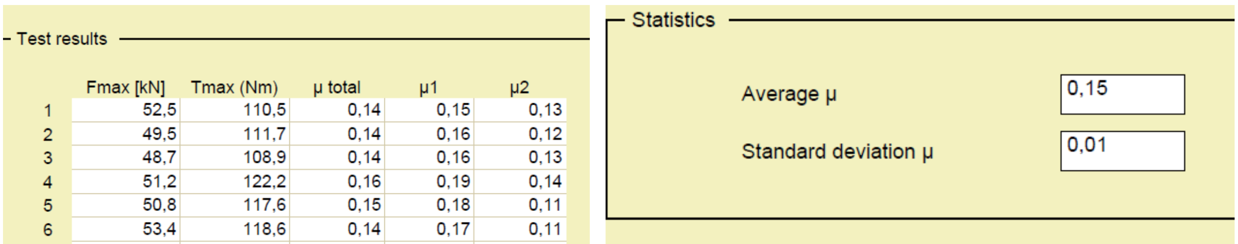


Figure 18. Part of a test report. The value entered in the test software to define the test parameters.

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 results

	Fmax [kN]	Tmax (Nm)	µ total	µ1	µ2
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
5	50,8	117,6	0,15	0,18	0,11
6	53,4	118,6	0,14	0,17	0,11

Statistics

Average µ	0,15
Standard deviation µ	0,01

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.

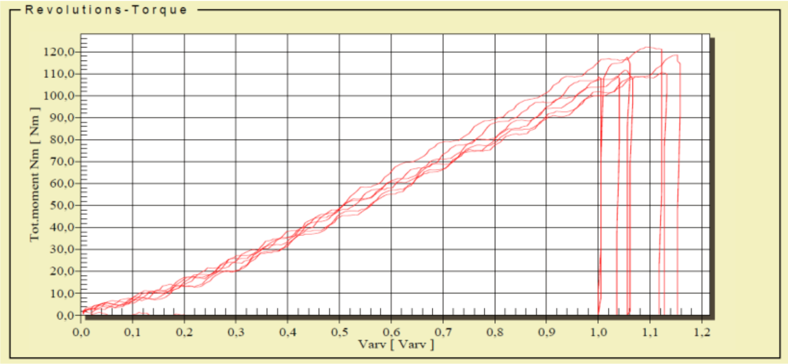


Figure 20. Revolution/torque diagram from the test report.

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.

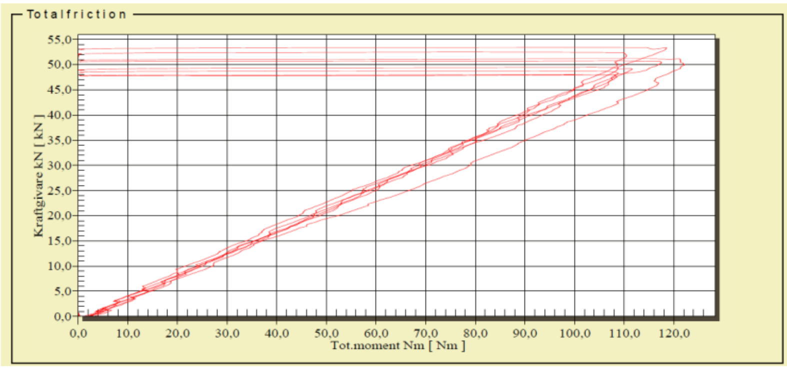


Figure 21. Torque/ preload diagram from the test report.

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.

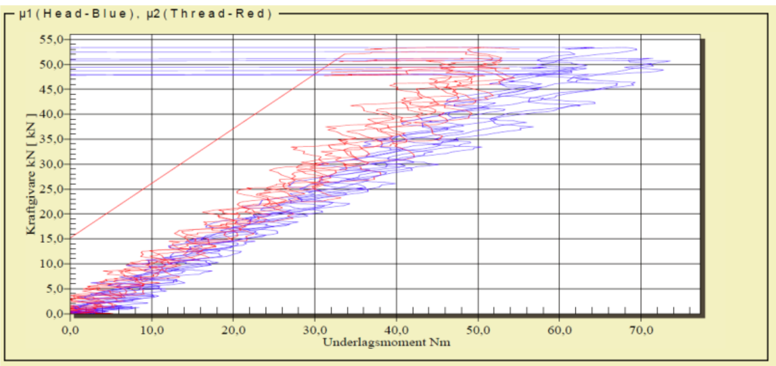


Figure 22. Torque/ preload diagram where the torque is split in head torque (blue) and thread torque (red).

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.

Table 7. The test series with plain fasteners.

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

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.

Table 8. The test series with electrically galvanized fasteners.

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

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.

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

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

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.

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.

Appendix

Contents

A1 Appendix 1 – Tightening methods

Table A8. Guide values for the tightening factor α_A

Tightening factor α_A	Scatter $\frac{\Delta F_M}{2 \cdot F_{Mm}} = \frac{\alpha_A - 1}{\alpha_A + 1}$	Tightening technique	Adjusting technique	Remarks	
1,05 to 1,2	±2 % to ±10 %	Elongation-controlled tightening with ultrasound	Echo time	• Calibrating values necessary • Allow for progressive increase in errors at $l_K/d < 2$ • Smaller errors with direct mechanical coupling, larger with indirect coupling	
1,1 to 1,5	±5 % to ±20 %	Mechanical elongation measurement	Adjustment via longitudinal measurement	• Exact determination of the axial elastic resilience of the bolt is necessary. The scatter depends substantially on the accuracy of the measuring technique. • Allow for progressive increase in errors at $l_K/d < 2$	
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 is substantially determined by the scatter in the bolt yield point. Here, the bolts are dimensioned for $F_{M\,min}$; a design of the bolts for $F_{M\,max}$ with the tightening factor α_A therefore does not apply to these tightening techniques.	
1,2 to 1,4	±9 % to ±17 %	Angle-controlled tightening, motor or manually operated	Experimental determination of pre-tightening torque and angle of rotation (steps)		
1,2 to 1,6	±9 % to ±23 %	Hydraulic tightening	Adjustment via length or pressure measurement	• Lower values for long bolts ($l_K/d \geq 5$) • Higher values for short bolts ($l_K/d \leq 2$)	
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 determination of required tightening torques on the original bolting part, e.g. by measuring bolt elongation	Lower values: large number of calibration 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. relatively stiff joints • relatively soft mating surface[1]) • mating surfaces which are not inclined to "seize", e.g. phosphated or with sufficient lubrication
1,6 to 2,0 (friction coefficient class B) 1,7 to 2,5 (friction coefficient class A)	±23 % to ±33 % ±26 % to ±43 %	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 coefficient (surface and lubricating conditions)	Lower values for: Measuring torque wrenches with steady tightening and for precision tightening spindles Higher values for: Signaling or automatic tripping torque wrenches	Higher values for: • large angles of rotation, i.e. relatively resilient joints and fine threads • high mating surface hardness combined with a rough surface
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 estimated friction coefficient) and an additional factor	Lower values for: • large number of calibration tests (re-tightening torque) • on the horizontal segment of the bolt characteristic • momentum transfer free from play	

[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 coefficient class	Range for μ_G and μ_K	Selection of typical examples for	
		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
B	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
C	0,14 to 0,24	austenitic steel	wax dispersions, pastes
		metallically bright phosphated	delivery state (lightly oiled)
		galvanic coatings such as Zn, Zn/Fe, Zn/Ni Zinc laminated coatings adhesive	none
D	0,20 to 0,35	austenitic steel	oil
		galvanic coatings such as Zn, Zn/Fe; hot-galvanized	none
E	≥ 0,30	galvanic coatings such as Zn/Fe, Zn/Ni austenitic steel Al, 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 at minor diameter	Kraft an der Mindest-Streckgrenze Load at the minimum yield point $F_{0.2\,min} = R_{p0.2min} \cdot A_S$ Festigkeitsklasse/Strength grade		
	P	d_2	A_S	A_{d_3}	8.8	10.9	12.9
	mm	mm	mm²	mm²	N	N	N
Metrisches Regelgewinde/Metric standard thread							
M4	0,7	3,545	8,78	7,749	5600	8300	9700
M5	0,8	4,480	14,2	12,69	9100	13300	15600
M6	1	5,350	20,1	17,89	12900	18900	22100
M7	1	6,350	28,9	26,18	18500	27000	32000
M8	1,25	7,188	36,6	32,84	23400	34500	40500
M10	1,5	9,026	58,0	52,30	37000	55000	64000
M12	1,75	10,863	84,3	76,25	54000	79000	93000
M14	2	12,701	115	104,7	74000	108000	127000
M16	2	14,701	157	144,1	100000	148000	173000
M18	2,5	16,376	193	175,1	127000	181000	212000
M20	2,5	18,376	245	225,2	162000	230000	270000
M22	2,5	20,376	303	281,5	200000	285000	335000
M24	3	22,051	353	324,3	233000	330000	390000
M27	3	25,051	459	427,1	305000	430000	500000
M30	3,5	27,727	561	519,0	370000	530000	620000
M33	3,5	30,727	694	647,2	460000	650000	760000
M36	4	33,402	817	759,3	540000	770000	900000
M39	4	36,402	976	913,0	640000	920000	1070000
Metrisches Feingewinde/Metric fine thread							
M8	1	7,350	39,2	36,03	25000	37000	43000
M9	1	8,350	51,0	47,45	32500	48000	56000
M10	1	9,350	64,5	60,45	41500	61000	71000
M10	1,25	9,188	61,2	56,29	39000	58000	67000
M12	1,25	11,188	92,1	86,03	59000	87000	101000
M12	1,5	11,026	88,1	81,07	56000	83000	97000
M14	1,5	13,026	125	116,1	80000	118000	138000
M16	1,5	15,026	167	157,5	107000	157000	184000
M18	1,5	17,026	216	205,1	143000	203000	238000
M18	2	16,701	204	189,8	135000	192000	224000
M20	1,5	19,026	272	259,0	180000	255000	300000
M22	1,5	21,026	333	319,2	220000	315000	365000
M24	1,5	23,026	401	385,7	265000	375000	440000
M24	2	22,701	384	364,6	255000	360000	420000
M27	1,5	26,026	514	497,2	340000	485000	570000
M27	2	25,701	496	473,2	325000	465000	550000
M30	1,5	29,026	642	622,8	425000	600000	710000
M30	2	28,701	621	596,0	410000	580000	680000
M33	1,5	32,026	784	762,6	520000	740000	860000
M33	2	31,701	761	732,8	500000	720000	840000
M36	2	34,701	915	883,8	580000	830000	970000
M36	3	34,051	865	820,4	570000	810000	950000
M39	2	37,701	1082	1049,0	714000	1010000	1190000
M39	3	37,051	1028	979,7	680000	970000	1130000

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)

Abmessung Size	**Steigung Pitch**	**Kerndurch-messer Minor diameter**	**Taillen-durchmesser Reduced-shank diameter**	**Taillen-querschnitt Reduced-shank cross section**	**Kraft an der Mindest-Streckgrenze Load at the minimum yield point** $F_{0,2min} = R_{p0,2min} \cdot \frac{\pi}{4}(0,9 \cdot d_3)^2$		
					Festigkeitsklasse/Strength grade		
	P	d_3	$d_T = 0,9 \cdot d_3$	$A_T = \frac{\pi}{4}(0,9 \cdot d_3)^2$	8.8	10.9	12.9
	mm	mm	mm	mm²	N	N	N
Metrisches Regelgewinde/Metric standard thread							
M4	0,7	3,141	2,83	6,28	4 000	5 900	6 900
M5	0,8	4,019	3,62	10,3	6 600	9 700	11 300
M6	1	4,773	4,30	14,5	9 300	13 600	15 900
M7	1	5,773	5,20	21,2	13 600	19 900	23 300
M8	1,25	6,466	5,82	26,6	17 000	25 000	29 500
M10	1,5	8,160	7,34	42,4	27 000	40 000	46 500
M12	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
M20	2,5	16,933	15,2	182	120 000	171 000	201 000
M22	2,5	18,933	17,0	228	151 000	214 000	250 000
M24	3	20,319	18,3	263	173 000	247 000	290 000
M27	3	23,319	21,0	346	228 000	325 000	380 000
M30	3,5	25,706	23,1	420	275 000	395 000	460 000
M33	3,5	28,706	25,8	524	345 000	495 000	580 000
M36	4	31,093	28,0	615	405 000	580 000	680 000
M39	4	34,093	30,7	739	490 000	700 000	810 000
Metrisches Feingewinde/Metric fine thread							
M8	1	6,773	6,10	29,2	18 700	27 500	32 000
M9	1	7,773	7,00	38,4	24 600	36 000	42 500
M10	1	8,773	7,90	49,0	31 500	46 000	54 000
M10	1,25	8,466	7,62	45,6	29 000	43 000	50 000
M12	1,25	10,466	9,42	69,7	44 500	66 000	77 000
M12	1,5	10,160	9,14	65,7	42 000	62 000	72 000
M14	1,5	12,160	10,94	94,1	60 000	88 000	103 000
M16	1,5	14,160	12,74	128	82 000	120 000	140 000
M18	1,5	16,160	14,54	166	110 000	156 000	183 000
M18	2	15,546	13,99	154	101 000	145 000	169 000
M20	1,5	18,160	16,34	210	138 000	197 000	231 000
M22	1,5	20,160	18,14	259	171 000	243 000	285 000
M24	1,5	22,160	19,94	312	206 000	295 000	345 000
M24	2	21,546	19,39	295	195 000	280 000	325 000
M27	1,5	25,160	22,64	403	265 000	380 000	445 000
M27	2	24,546	22,09	383	255 000	360 000	420 000
M30	1,5	28,160	25,34	504	335 000	475 000	550 000
M30	2	27,546	24,79	483	320 000	455 000	530 000
M33	1,5	31,160	28,04	618	410 000	580 000	680 000
M33	2	30,546	27,49	594	390 000	560 000	650 000
M36	2	33,546	30,19	716	470 000	670 000	780 000
M36	3	32,319	29,09	664	440 000	620 000	730 000
M39	2	36,546	32,89	850	561 000	799 000	935 000
M39	3	35,319	31,79	794	520 000	750 000	870 000

A4 Appendix 4 – Calculation of tolerance influence

$F_M := 54kN$

$P := 1.75mm$

$d_{2minustolerance} := 10.679mm$

$d_{2plustolerance} := 10.829mm$

$D_{Km} := \frac{19 + 12}{2} mm$

$\mu_G := 0.12$

$\mu_K := 0.12$

$$M_a := F_M \cdot \left(0.16 \cdot P + 0.58 \cdot d_{2minustolerance} \cdot \mu_G + \frac{D_{Km}}{2} \cdot \mu_K \right)$$

$$M_a \rightarrow 54 \cdot kN \cdot (0.7432584mm + 0.93mm + 0.28mm) = 105.476N \cdot m$$

$$M_a := F_M \cdot \left(0.16 \cdot P + 0.58 \cdot d_{2plustolerance} \cdot \mu_G + \frac{D_{Km}}{2} \cdot \mu_K \right)$$

$$M_a \rightarrow 54 \cdot kN \cdot (0.7536984mm + 0.93mm + 0.28mm) = 106.04N \cdot m$$

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

A5 Appendix 5 – Test data

A5.1 Plain without oil

T E S T R E S U L T S 2013-11-25-14-32-08

Customer

Customer: Bachelor - frictiontest

Test data

Test type: Separate Head and Thread friction

Measure RPM: 10

Misc. test data (Lubrication, washer type etc): Proof load: 48,9kN

Bolt data

Dimension	M12	Length	-
Strength	8		
Surf.Treat.	Plain, oil removed		
Head	WAF: 18mm		
Pitch(P)	1,75	D0	17,25
d2	10,863	dh	13,2

Misc. bolt data

Test results

	Fmax [kN]	Tmax (Nm)	μ total	μ1	μ2
1	54,0	160,7	0,16	0,16	0,16
2	53,2	139,0	0,16	0,15	0,17
3	53,7	196,9	0,16	0,17	0,16
4	56,7	129,4	0,14	0,14	0,13
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	0,15	0,12
8	54,8	141,9	0,14	0,14	0,13
9	54,9	132,5	0,14	0,14	0,13
10	53,6	175,3	0,17	0,19	0,15
11	54,8	155,9	0,17	0,17	0,16
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
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	0,25
19	52,4	191,8	0,18	0,15	0,21
20	54,1	153,6	0,18	0,18	0,18
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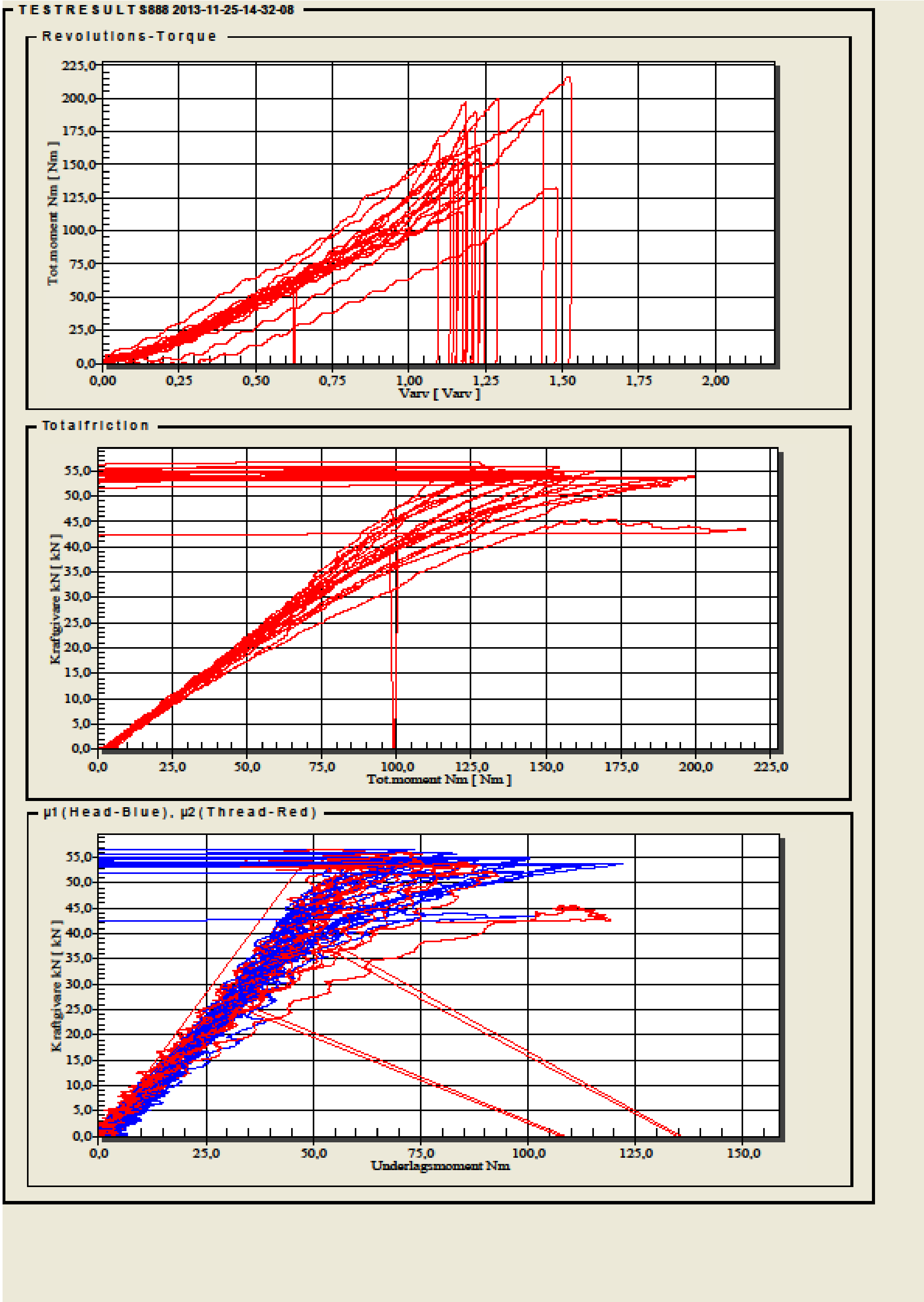
Statistics

Average μ: 0,16

Standard deviation μ: 0,02


T E S T R E S U L T S888 2013-11-25-14-32-08
Revolutions-Torque
Tot.moment Nm [Nm]
Varv [Varv]
Totalfriction
Kraftgivare kN [kN]
Tot.moment Nm [Nm]
μ1(Head-Blue), μ2(Thread-Red)
Kraftgivare kN [kN]
Underlagsmoment Nm

A5.2 Plain oiled

T E S T R E S U L T S 2013-11-25-14-00-43

Customer

Customer

Bachelor - frictiontest

Test data

Test type: Separate Head and Thread friction

Measure RPM: 10

Misc. test data (Lubrication, washer type etc)

Proof load: 48,9kN

Bolt data

Dimension	M12	Length	-
Strength	8		
Surf.Treat.	Plain, oiled		
Head	WAF: 18mm		
Pitch(P)	1,75	D0	17,25
d2	10,863	dh	13,2

Misc. bolt data

Test results

	Fmax [kN]	Tmax (Nm)	µ total	µ1	µ2
1	55,7	117,6	0,14	0,14	0,13
2	54,5	106,3	0,12	0,14	0,10
3	56,2	107,9	0,13	0,13	0,13
4	55,3	149,4	0,14	0,15	0,13
5	54,8	119,6	0,14	0,15	0,14
6	54,9	122,0	0,14	0,15	0,14
7	55,8	119,9	0,14	0,14	0,14
8	55,7	116,3	0,14	0,15	0,12
9	52,8	114,4	0,14	0,14	0,13
10	55,0	118,9	0,14	0,14	0,14
11					
12					
13					
14					
15					
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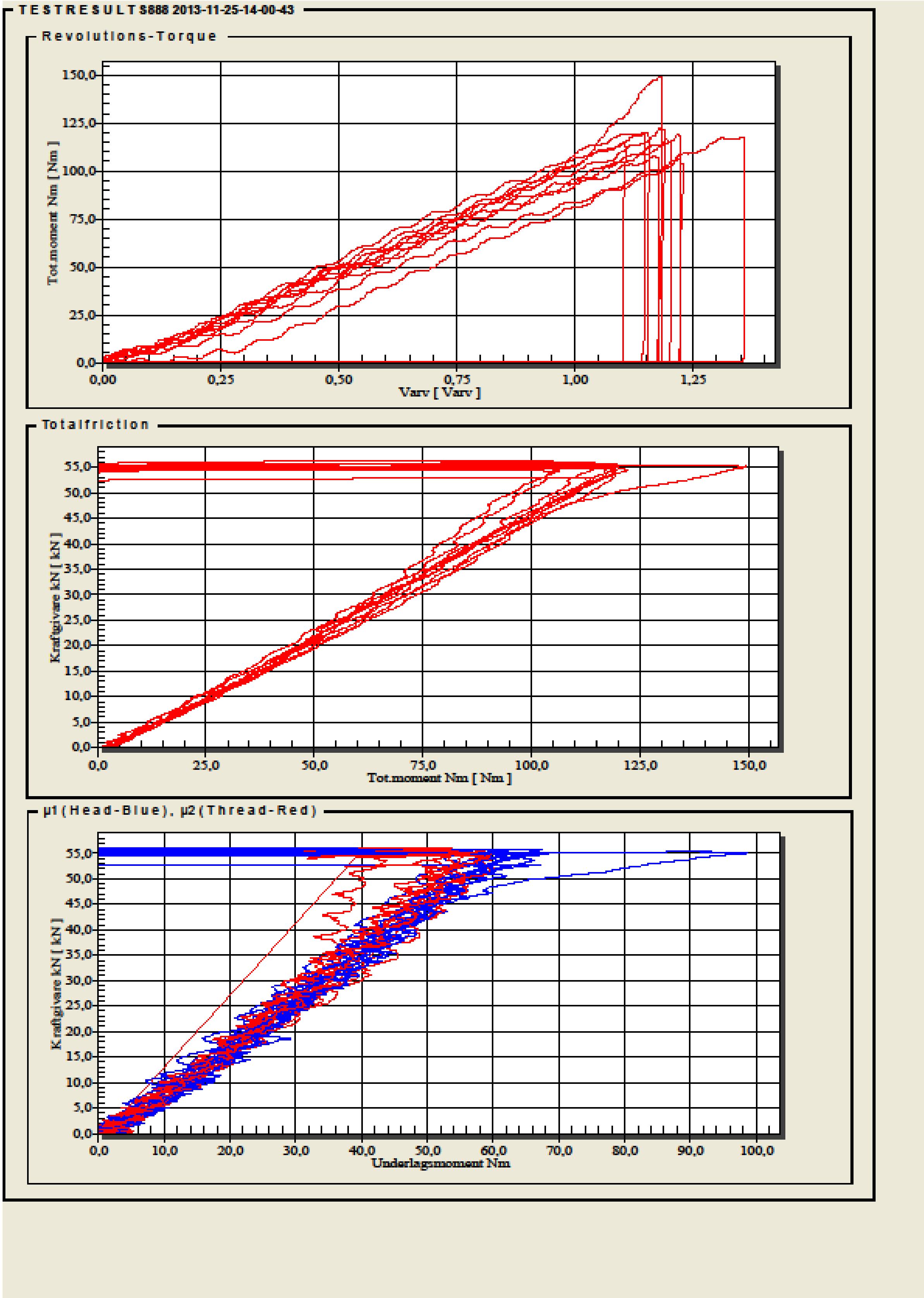
29					
30					

Statistics

Average µ: 0,14

Standard deviation µ: 0,01


TESTRESULT S888 2013-11-25-14-00-43
Revolutions-Torque
Tot.moment Nm [Nm]
Varv [Varv]
Totalfriction
Kraftgivare kN [kN]
Tot.moment Nm [Nm]
μ1(Head-Blue), μ2(Thread-Red)
Kraftgivare kN [kN]
Underlagsmoment Nm

A5.3 Plain, oiled with G-Rapid +

T E S T R E S U L T S 2013-11-27-10-29-44

Customer

Customer

Bachelor - Frictiontest

Test data

Test type: Separate Head and Thread friction

Measure RPM: 10

Misc. test data (Lubrication, washer type etc)

Lubricated with G-Rapid +
Proof load: 48,9kN

Bolt data

Dimension	M12	Length	-
Strength	8		
Surf.Treat.	Plain, oiled		
Head	WAF: 18mm		
Pitch(P)	1,75	D0	17,25
d2	10,863	dh	13,2

Misc. bolt data

Test results

	Fmax [kN]	Tmax (Nm)	µ total	µ1	µ2
1	49,4	75,4	0,10	0,10	0,10
2	54,3	78,2	0,09	0,10	0,07
3	52,1	77,0	0,09	0,11	0,07
4	51,6	80,9	0,10	0,12	0,07
5	52,7	85,9	0,10	0,10	0,10
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
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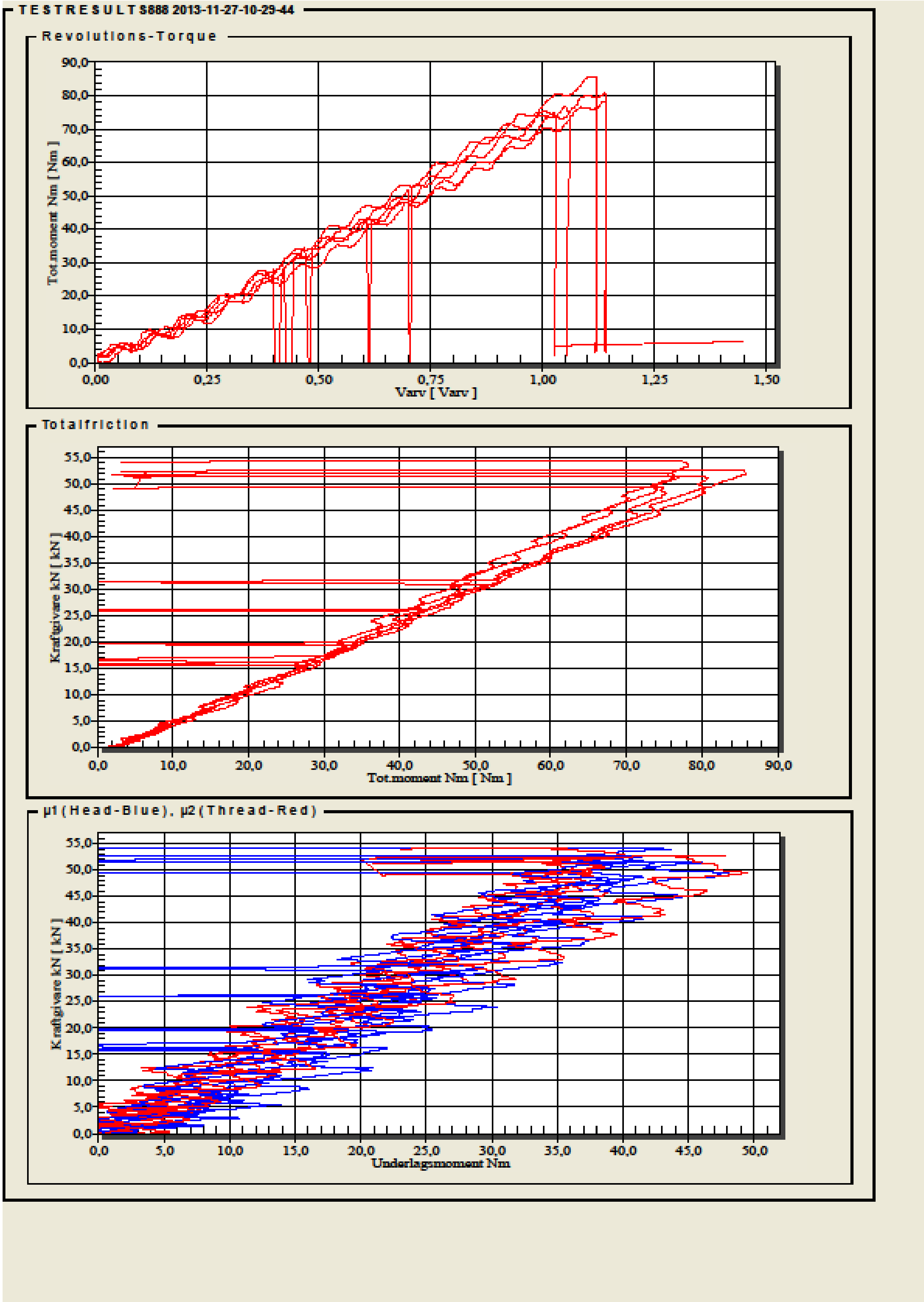
30					

Statistics

Average µ: 0,10

Standard deviation µ: 0,01


TESTRESULT S888 2013-11-27-10-29-44
Revolutions-Torque
Tot.moment Nm [Nm]
Varv [Varv]
Totalfriction
Kraftgivare kN [kN]
Tot.moment Nm [Nm]
µ1(Head-Blue), µ2(Thread-Red)
Kraftgivare kN [kN]
Underlagsmoment Nm

A5.4 Plain, oiled with Molykote 1000

T E S T R E S U L T S 2013-11-27-10-13-10

Customer

Customer

Bachelor - frictiontest

Test data

Test type: Separate Head and Thread friction

Measure RPM: 10

Misc. test data (Lubrication, washer type etc)

Lubricated with Molykote 1000
Proof load: 48,9kN

Bolt data

Dimension	M12	Length	-
Strength	8		
Surf.Treat.	Plain, oiled		
Head	WAF: 18mm		
Pitch(P)	1,75	D0	17,25
d2	10,863	dh	13,2

Misc. bolt data

Test results

	Fmax [kN]	Tmax (Nm)	μ total	μ1	μ2
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
5	50,8	117,6	0,15	0,18	0,11
6	53,4	118,6	0,14	0,17	0,11
7					
8					
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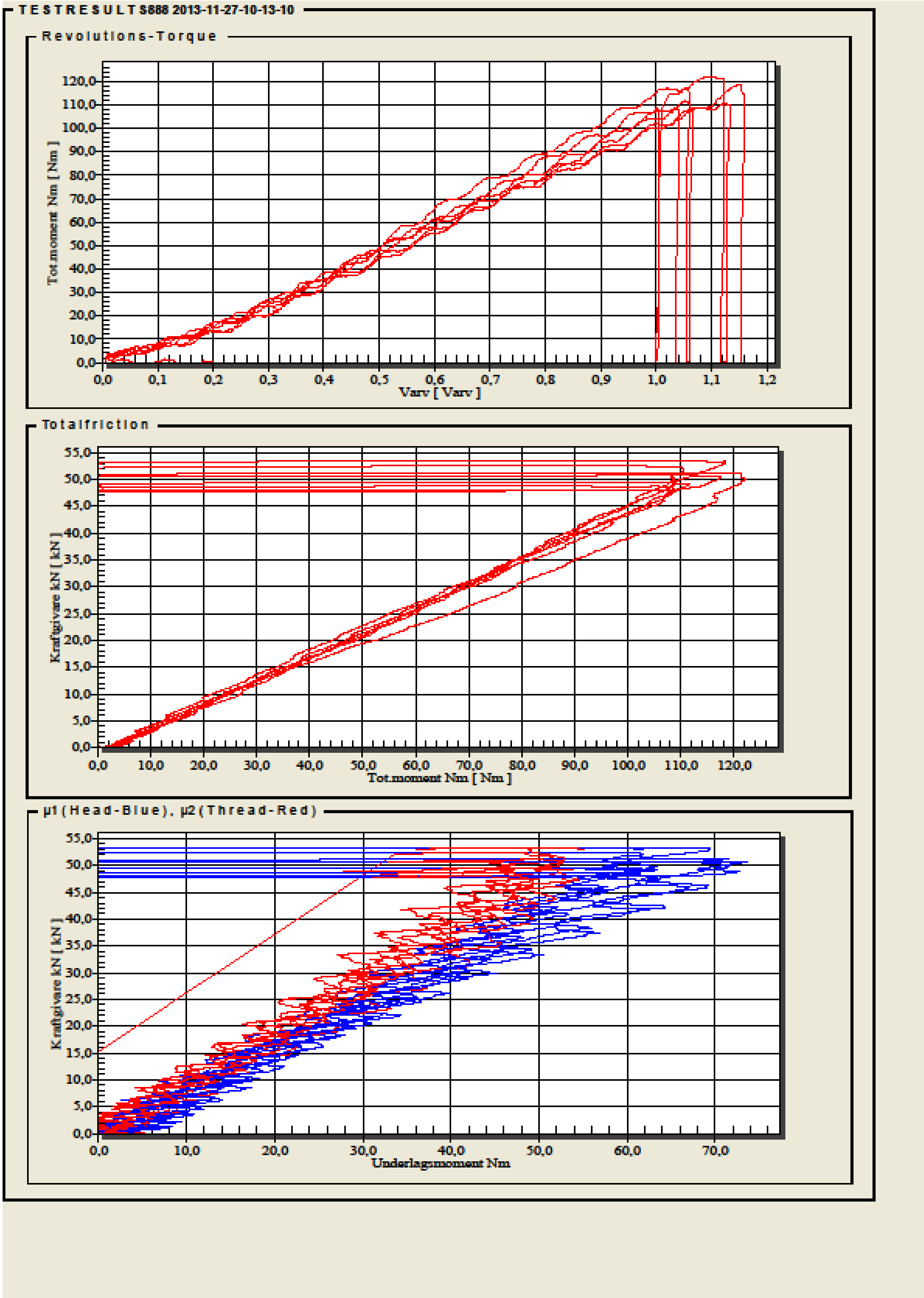
Statistics

Average μ: 0,15

Standard deviation μ: 0,01


TESTRESULTS 888 2013-11-27-10-13-10
Revolutions-Torque
Tot.moment Nm [Nm]
Varv [Varv]
Totalfriction
Kraftgivare kN [kN]
Tot.moment Nm [Nm]
µ1(Head-Blue), µ2(Thread-Red)
Kraftgivare kN [kN]
Underlagsmoment Nm

A5.5 FZB, no lubrication

T E S T R E S U L T S 2013-11-26-09-00-29

Customer

Customer

Bachelor - frictiontest

Test data

Test type: Separate Head and Thread friction

Measure RPM: 10

Misc. test data (Lubrication, washer type etc)

No lubrication
Proof load: 48,9kN

Bolt data

Dimension: M12
Length: -
Strength: 8
Surf.Treat.: FZB
Head: WAP: 18mm
Pitch(P): 1,75
D0: 17,25
d2: 10,863
dh: 13,2

Misc. bolt data

Test results

	Fmax [kN]	Tmax (Nm)	μ total	μ1	μ2
1	53,8	124,0	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
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
8	38,8	206,3	0,28	0,22	0,35
9	47,7	216,3	0,26	0,27	0,25
10	46,7	217,1	0,22	0,20	0,26
11	42,5	226,7	0,26	0,21	0,33
12	42,7	211,6	0,24	0,20	0,30
13	42,2	214,7	0,28	0,25	0,32
14	43,1	210,8	0,24	0,18	0,31
15	48,3	218,1	0,27	0,31	0,23
16	42,1	233,5	0,27	0,21	0,33
17	43,9	216,9	0,26	0,22	0,31
18	45,7	202,8	0,23	0,21	0,26
19	42,7	228,3	0,29	0,27	0,30
20	43,3	232,4	0,29	0,24	0,35
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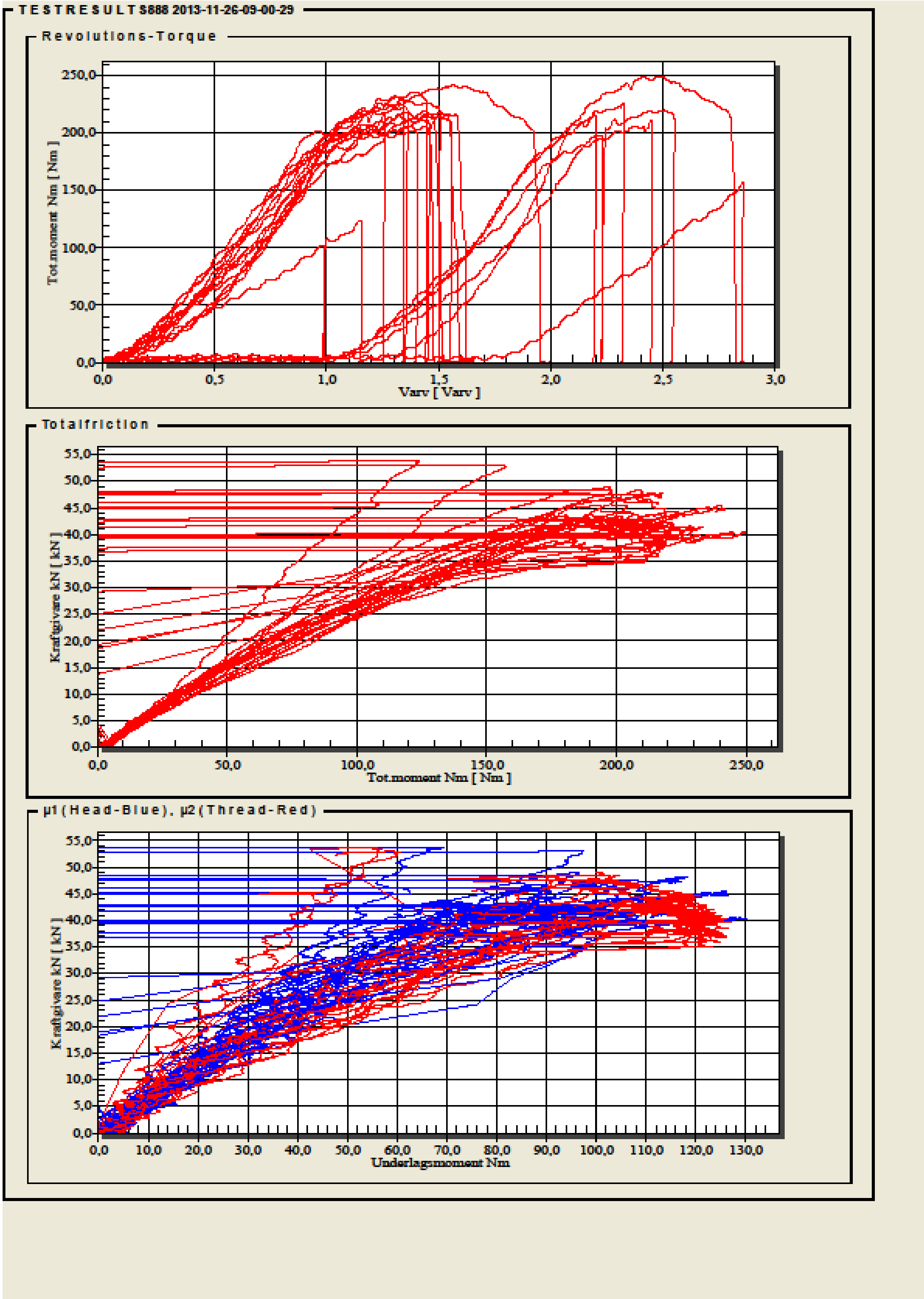
Statistics

Average μ: 0,25

Standard deviation μ: 0,04



TESTRESULT S888 2013-11-26-09-00-29
Revolutions-Torque
Tot.moment Nm [Nm]
Varv [Varv]
Totalfriction
Kraftgivare kN [kN]
Tot.moment Nm [Nm]
μ1(Head-Blue), μ2(Thread-Red)
Kraftgivare kN [kN]
Underlagsmoment Nm

A5.6 FZB, with G-Rapid +

T E S T R E S U L T S 2013-11-26-11-42-50

Customer

Customer

Bachelor - frictiontest

Test data

Test type: Separate Head and Thread friction

Measure RPM: 10

Misc. test data (Lubrication, washer type etc)

Lubricated with G-Rapid +
Proof load: 48,9kN

Bolt data

Dimension	M12	Length	-
Strength	8		
Surf.Treat.	FZB		
Head	WAP: 18mm		
Pitch(P)	1,75	D0	17,25
d2	10,863	dh	13,2

Misc. bolt data

Test results

	Fmax [kN]	Tmax (Nm)	μ total	μ1	μ2
1	53,8	75,5	0,09	0,12	0,06
2	53,6	82,6	0,10	0,12	0,06
3	53,5	77,9	0,09	0,12	0,06
4	51,8	77,3	0,09	0,11	0,08
5	53,4	79,5	0,09	0,12	0,06
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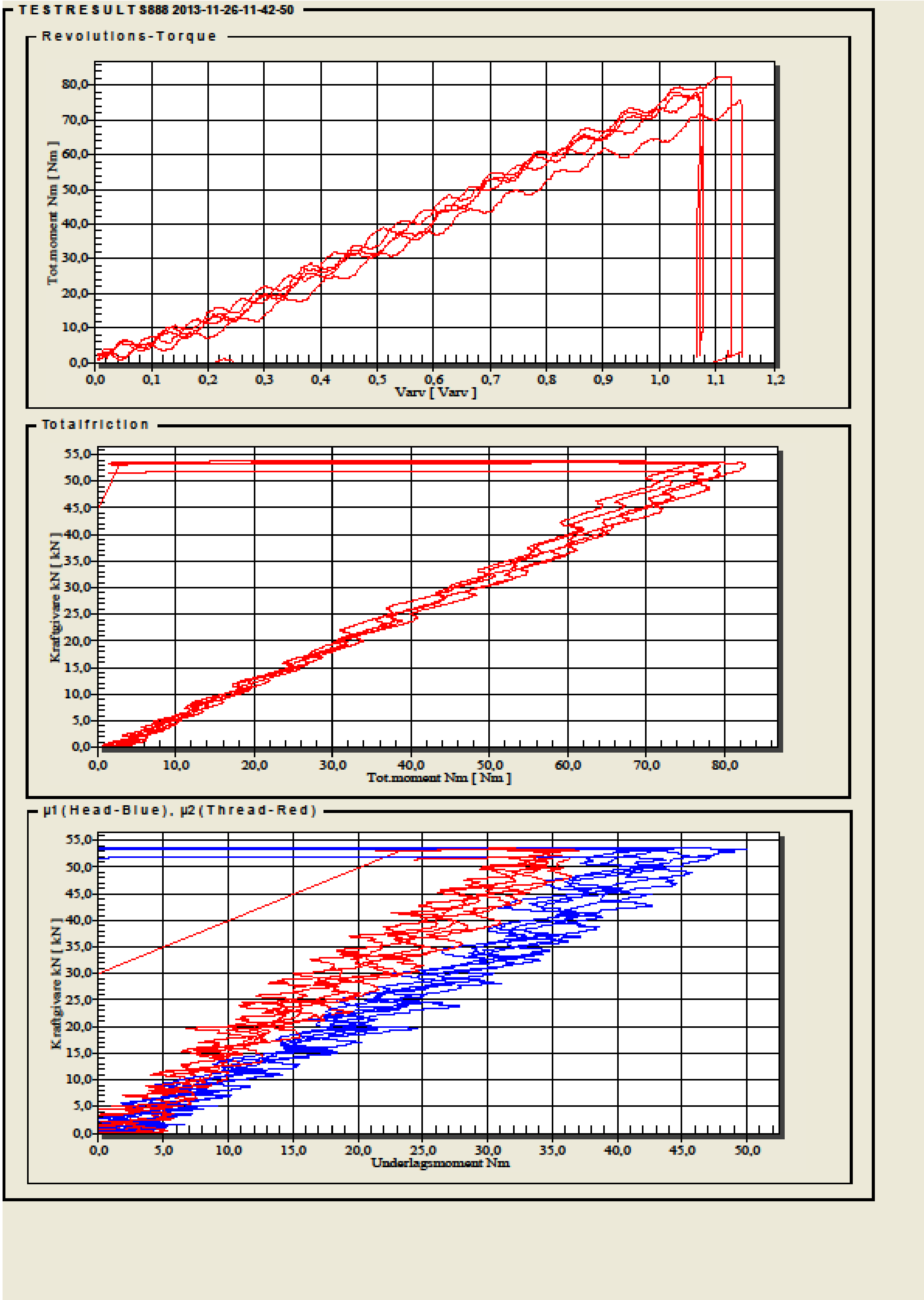
Statistics

Average μ: 0,09

Standard deviation μ: 0,00


TESTRESULT S888 2013-11-26-11-42-50
Revolutions-Torque
Tot.moment Nm [Nm]
Varv [Varv]
Totalfriction
Kraftgivare kN [kN]
Tot.moment Nm [Nm]
µ1(Head-Blue), µ2(Thread-Red)
Kraftgivare kN [kN]
Underlagsmoment Nm

A5.7 FZB, with Molykote 1000

T E S T R E S U L T S 2013-11-26-10-55-21

Customer

Customer: Bachelor - Frictiontest

Test data

Test type: Separate Head and Thread friction

Measure RPM: 10

Misc. test data (Lubrication, washer type etc):
Lubricated with Molykote 1000
Proof load: 48,9kN

Bolt data

Dimension	M12	Length	-
Strength	8		
Surf.Treat.	FZB		
Head	WAP: 18mm		
Pitch(P)	1,75	D0	17,25
d2	10,863	dh	13,2

Misc. bolt data

Test results

	Fmax [kN]	Tmax (Nm)	μ total	μ1	μ2
1	55,3	83,4	0,09	0,10	0,09
2	53,9	83,3	0,09	0,10	0,08
3	55,2	80,0	0,09	0,11	0,08
4	55,4	86,8	0,10	0,10	0,08
5	55,6	90,7	0,11	0,11	0,10
6	53,7	83,9	0,10	0,12	0,07
7	53,4	80,3	0,09	0,10	0,08
8	55,1	82,4	0,09	0,12	0,07
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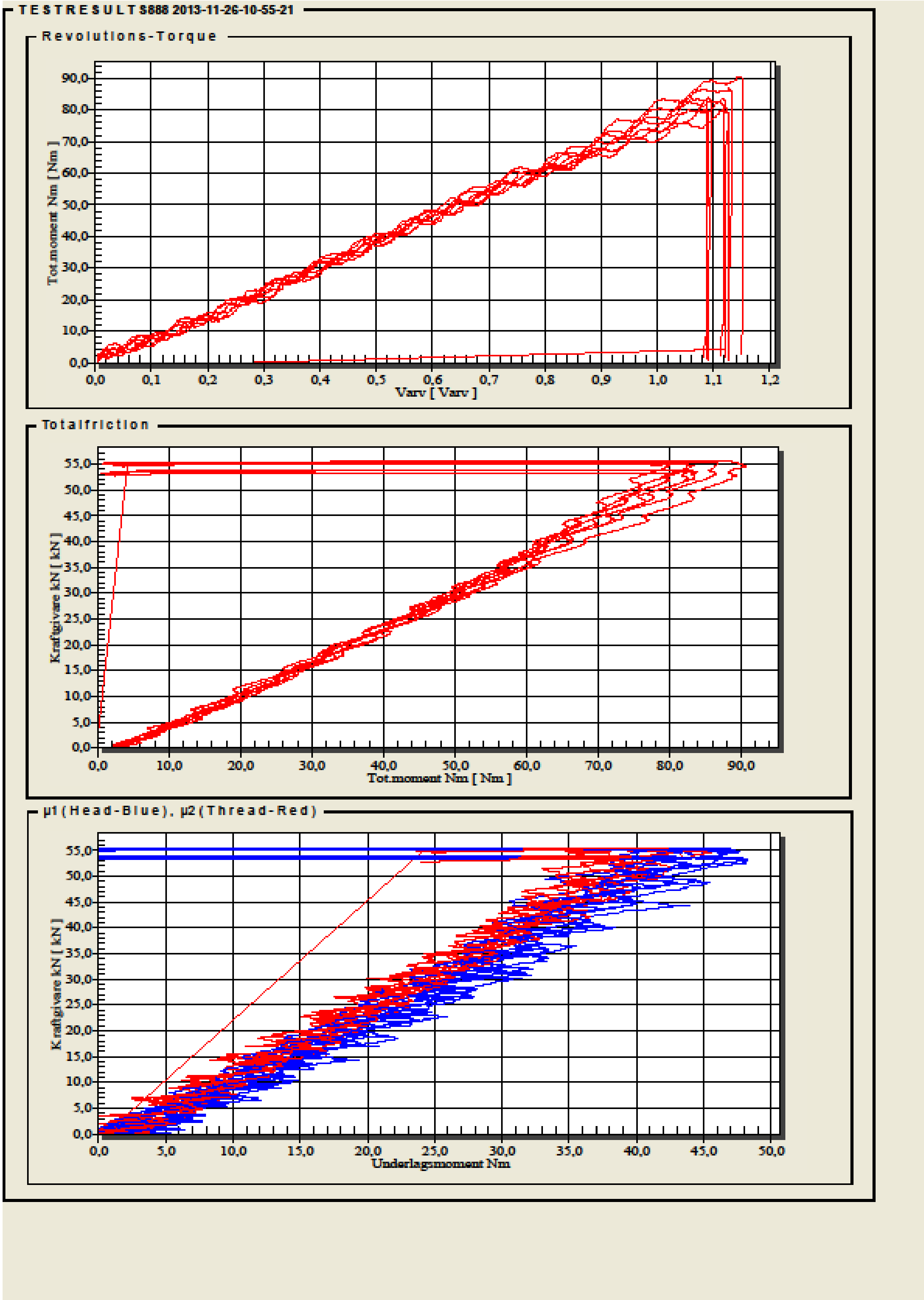
Statistics

Average μ: 0,10

Standard deviation μ: 0,01


T E S T R E S U L T S888 2013-11-26-10-55-21
Revolutions-Torque
90,0 80,0 70,0 60,0 50,0 40,0 30,0 20,0 10,0 0,0
Tot.moment Nm [Nm]
0,0 0,1 0,2 0,3 0,4 0,5 0,6 0,7 0,8 0,9 1,0 1,1 1,2
Varv [Varv]
Totalfriction
55,0 50,0 45,0 40,0 35,0 30,0 25,0 20,0 15,0 10,0 5,0 0,0
Kraftgivare kN [kN]
0,0 10,0 20,0 30,0 40,0 50,0 60,0 70,0 80,0 90,0
Tot.moment Nm [Nm]
μ1(Head-Blue), μ2(Thread-Red)
55,0 50,0 45,0 40,0 35,0 30,0 25,0 20,0 15,0 10,0 5,0 0,0
Kraftgivare kN [kN]
0,0 5,0 10,0 15,0 20,0 25,0 30,0 35,0 40,0 45,0 50,0
Underlagsmoment Nm

A5.8 FZB, with Gleitmo 605

TESTRESULTS 2013-11-27-13-23-48

Customer

Customer: Bachelor - Frictionstest

Test data

Test type: Separate Head and Thread friction

Measure RPM: 10

Misc. test data (Lubrication, washer type etc):
Lubricated with Gleitmo 605 1:5
Proof load: 48,9kN

Bolt data

Dimension	M12	Length	-
Strength	8		
Surf.Treat.	FZB		
Head	WAP: 18mm		
Pitch(P)	1,75	D0	17,25
d2	10,863	dh	13,2

Misc. bolt data

Test results

	Fmax [kN]	Tmax (Nm)	µ total	µ1	µ2
1	54,4	95,3	0,11	0,17	0,05
2	51,1	100,3	0,12	0,18	0,05
3	54,3	126,8	0,14	0,20	0,07
4	51,7	86,5	0,12	0,16	0,07
5	53,5	105,8	0,13	0,19	0,07
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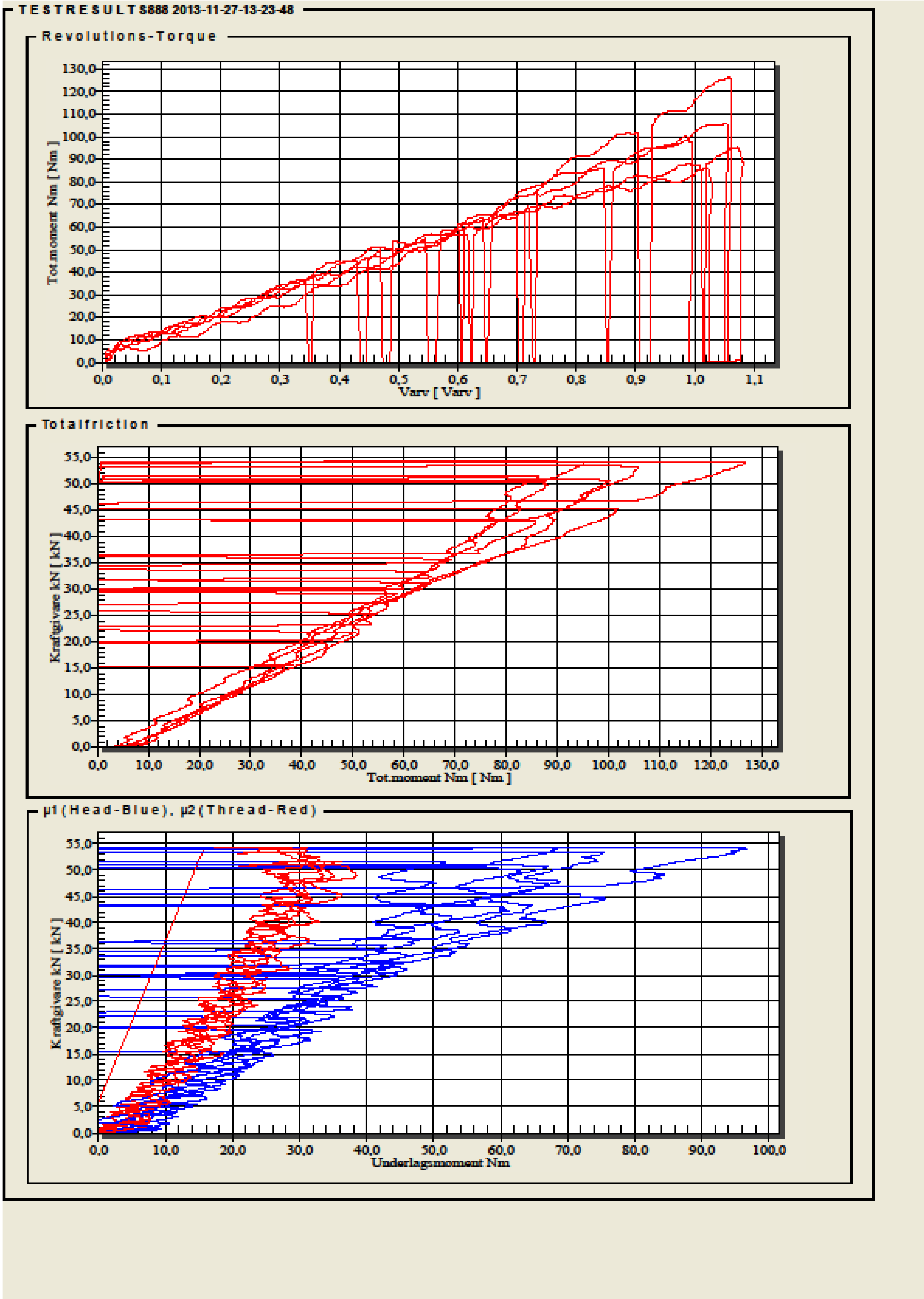
Statistics

Average µ: 0,12

Standard deviation µ: 0,01



TESTRESULTS888 2013-11-27-13-23-48
Revolutions-Torque
Tot.moment Nm [Nm]
Varv [Varv]
Totalfriction
Kraftgivare kN [kN]
Tot.moment Nm [Nm]
μ1(Head-Blue), μ2(Thread-Red)
Kraftgivare kN [kN]
Underlagsmoment Nm

A5.9 FZV, no lubrication

T E S T R E S U L T S 2013-11-26-14-06-19

Customer

Customer: Bachelor - Frictiontest

Test data

Test type: Separate Head and Thread friction

Measure RPM: 10

Misc. test data (Lubrication, washer type etc):
No lubrication, oil remove on nut
Proof load: 48,9kN

Bolt data

Dimension	M12	Length	-
Strength	8		
Surf.Treat.	FZV		
Head	WAP: 18mm		
Pitch(P)	1,75	D0	17,25
d2	10,863	dh	13,2

Misc. bolt data

Test results

	Fmax [kN]	Tmax (Nm)	µ total	µ1	µ2
1	47,1	166,3	0,20	0,21	0,19
2	50,5	138,9	0,15	0,14	0,17
3	54,2	122,2	0,14	0,15	0,13
4	54,0	109,1	0,13	0,15	0,10
5	55,5	124,4	0,13	0,15	0,12
6	51,1	120,9	0,15	0,17	0,12
7	54,1	125,0	0,14	0,15	0,13
8	54,6	117,3	0,13	0,15	0,11
9	50,2	149,0	0,17	0,18	0,16
10	42,6	178,0	0,23	0,18	0,29
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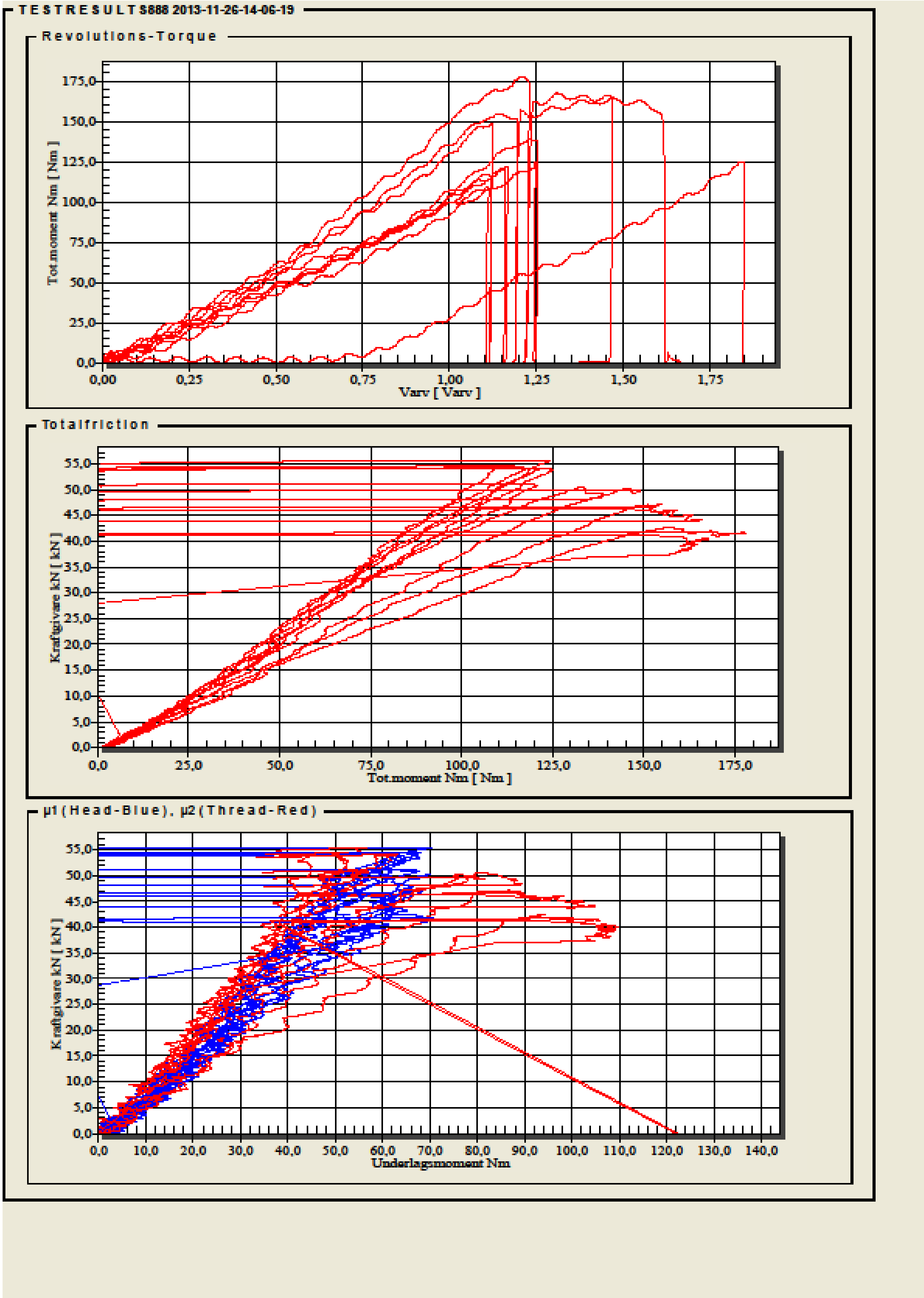
Statistics

Average µ: 0,16

Standard deviation µ: 0,03


TESTRESULTS888 2013-11-26-14-06-19
Revolutions-Torque
Tot.moment Nm [Nm]
Varv [Varv]
Totalfriction
Kraftgivare kN [kN]
Tot.moment Nm [Nm]
μ1(Head-Blue), μ2(Thread-Red)
Kraftgivare kN [kN]
Underlagsmoment Nm

A5.10 FZV, oiled

T E S T R E S U L T S 2013-11-26-13-28-07

Customer

Customer: Bachelor - Frictiontest

Test data

Test type: Separate Head and Thread friction

Measure RPM: 10

Misc. test data (Lubrication, washer type etc):
Without lubrication
Proof load: 48,9kN

Bolt data

Dimension	M12	Length	-
Strength	8		
Surf.Treat.	FZV		
Head	WAP: 18mm		
Pitch(P)	1,75	D0	17,25
d2	10,863	dh	13,2

Misc. bolt data

Test results

	Fmax [kN]	Tmax (Nm)	µ total	µ1	µ2
1	53,2	90,3	0,11	0,12	0,10
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	0,08
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
9	54,7	88,9	0,11	0,11	0,10
10	52,4	94,9	0,12	0,13	0,10
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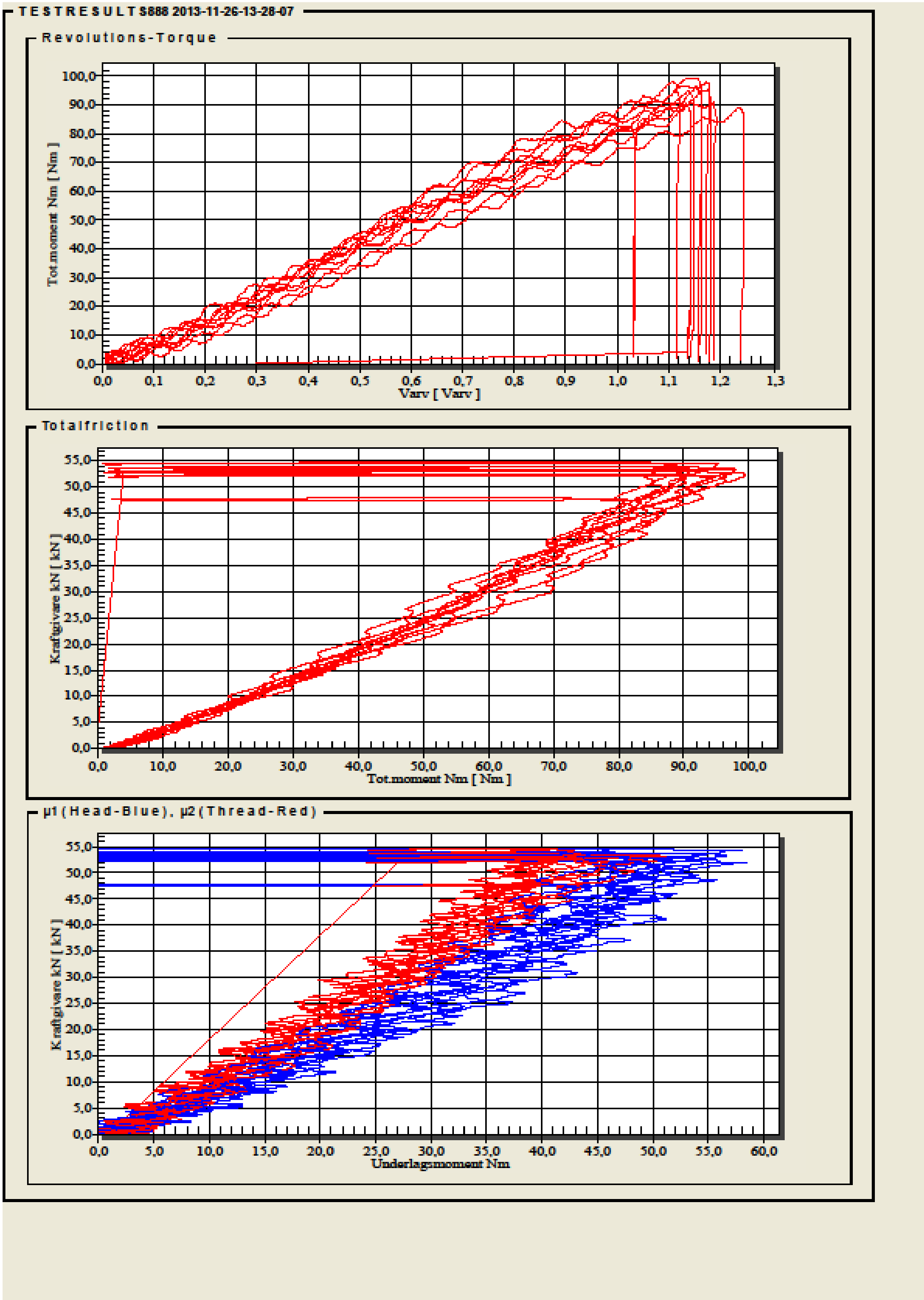
Statistics

Average µ: 0,12

Standard deviation µ: 0,01


TESTRESULTS888 2013-11-26-13-28-07
Revolutions-Torque
Tot.moment Nm [Nm]
Varv [Varv]
Totalfriction
Kraftgivare kN [kN]
Tot.moment Nm [Nm]
µ1(Head-Blue), µ2(Thread-Red)
Kraftgivare kN [kN]
Underlagsmoment Nm

A5.11 FZV, G-rapid +

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

Customer

Customer

Bachelor - Frictiontest

Test data

Test type: Separate Head and Thread friction

Measure RPM: 10

Misc. test data (Lubrication, washer type etc)

Lubricated with G-rapid +
Proof load: 48,9kN

Bolt data

Dimension	M12	Length	-
Strength	8		
Surf.Treat.	FZV		
Head	WAP: 18mm		
Pitch(P)	1,75	D0	17,25
d2	10,863	dh	13,2

Misc. bolt data

Test results

	Fmax [kN]	Tmax (Nm)	μ total	μ1	μ2
1	52,0	85,6	0,10	0,13	0,07
2	52,1	85,1	0,10	0,13	0,07
3	53,9	82,8	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
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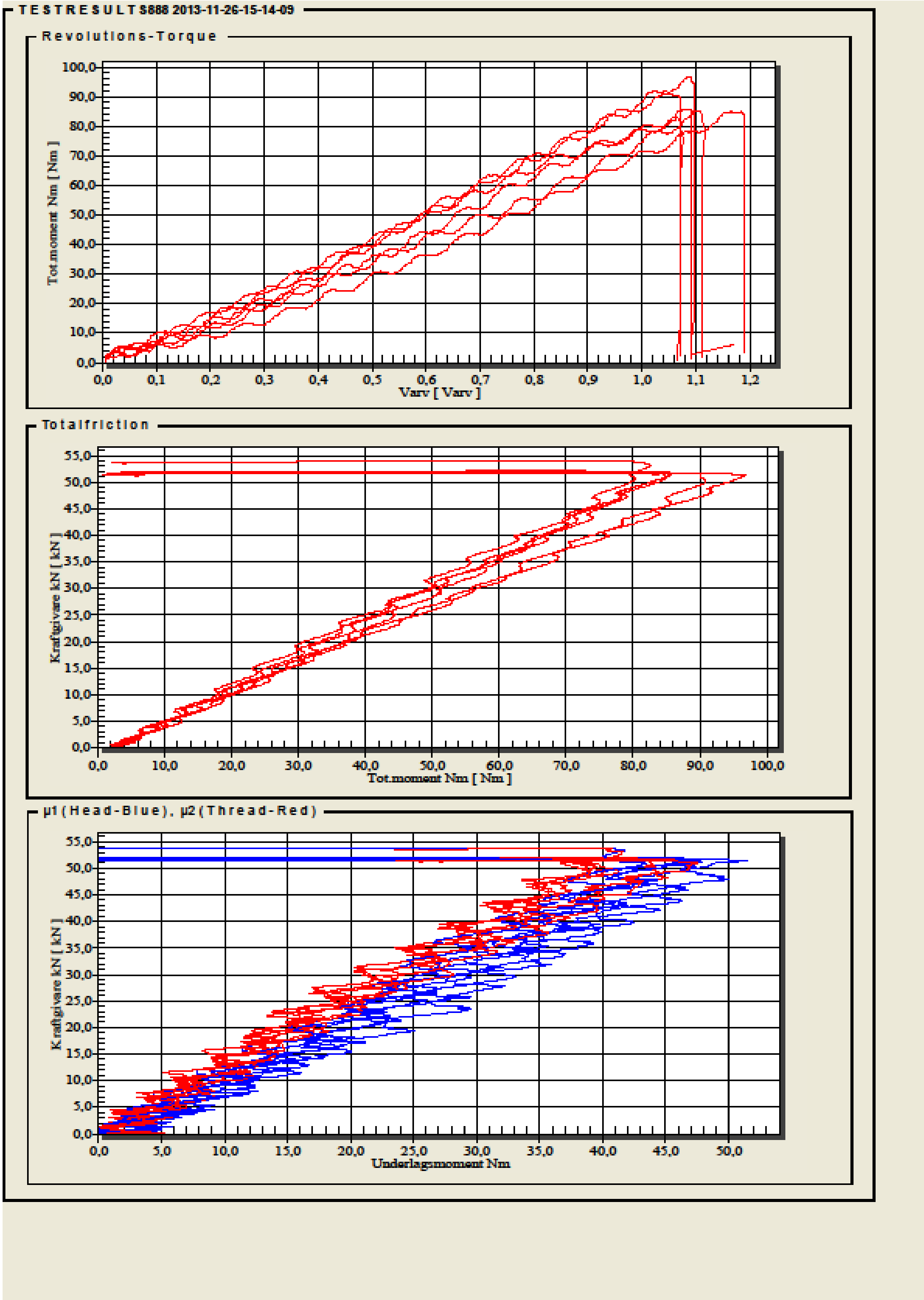
Statistics

Average μ: 0,11

Standard deviation μ: 0,01


TESTRESULTS888 2013-11-26-15-14-09
Revolutions-Torque
Tot.moment Nm [Nm]
Varv [Varv]
Totalfriction
Kraftgivare kN [kN]
Tot.moment Nm [Nm]
µ1(Head-Blue), µ2(Thread-Red)
Kraftgivare kN [kN]
Underlagsmoment Nm

A5.12 FZV, Molykote 1000

T E S T R E S U L T S 2013-11-26-14-37-09

Customer

Customer

Bachelor - frictiontest

Test data

Test type: Separate Head and Thread friction

Measure RPM: 10

Misc. test data (Lubrication, washer type etc)

Lubricated with Molykote 100.
Proof load: 48,9kN

Bolt data

Dimension	M12	Length	-
Strength	8		
Surf.Treat.	FZV		
Head	WAP: 18mm		
Pitch(P)	1,75	D0	17,25
d2	10,863	dh	13,2

Misc. bolt data

Test results

	Fmax [kN]	Tmax (Nm)	µ total	µ1	µ2
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	104,3	0,13	0,15	0,11
4	52,5	95,5	0,12	0,14	0,10
5	51,5	104,2	0,13	0,15	0,11
6	56,3	98,6	0,11	0,13	0,10
7	51,1	98,1	0,12	0,15	0,10
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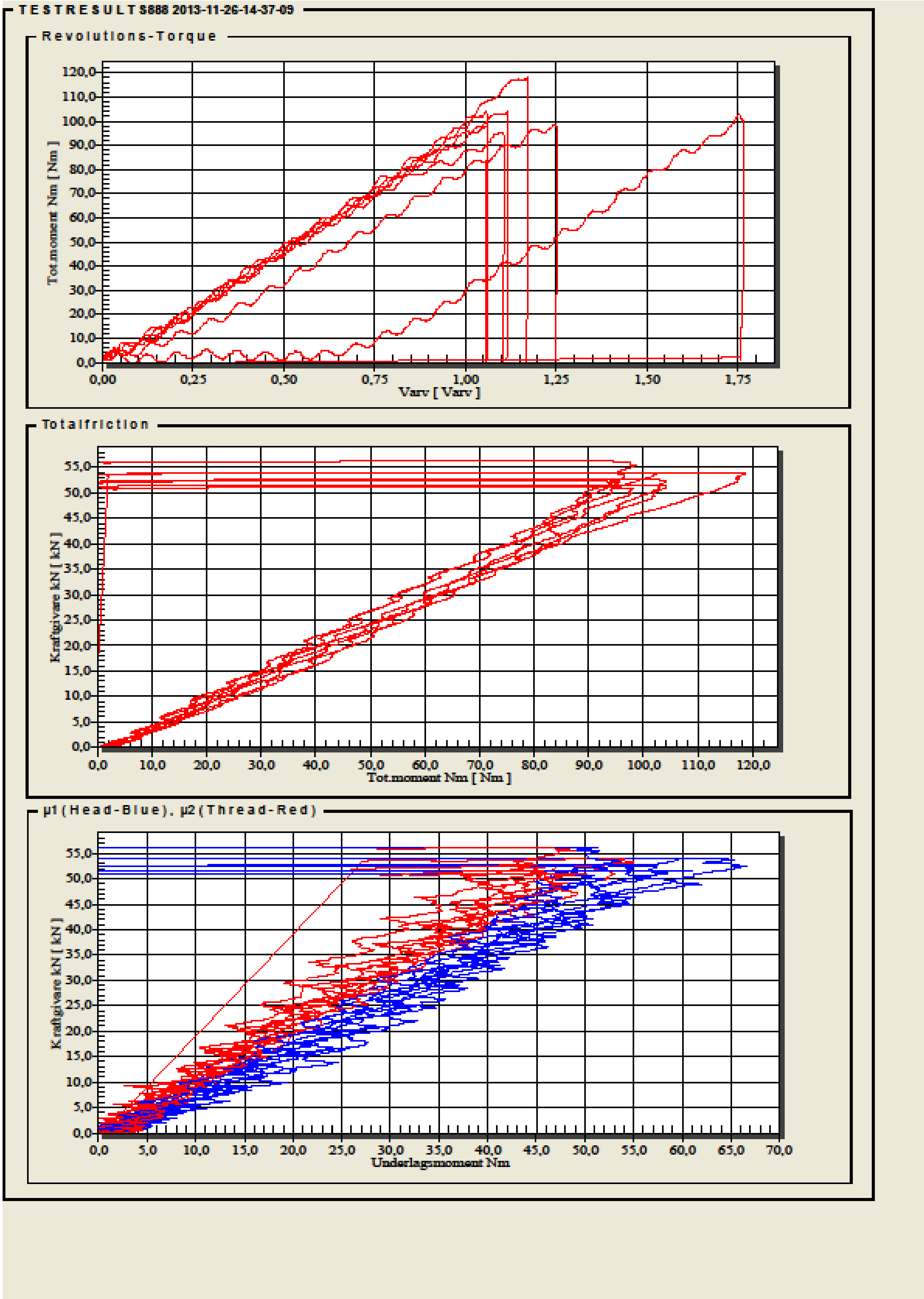
Statistics

Average µ: 0,12

Standard deviation µ: 0,01


TESTRESULTS888 2013-11-26-14-37-09
Revolutions-Torque
Tot.moment Nm [Nm]
Varv [Varv]
Totalfriction
Kraftgivare kN [kN]
Tot.moment Nm [Nm]
µ1(Head-Blue), µ2(Thread-Red)
Kraftgivare kN [kN]
Underlagsmoment Nm

A5.13 A4-80, no lubrication

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

Customer

Customer: Bachelor - Frictiontest

Test data

Test type: Separate Head and Thread friction

Measure RPM: 10

Misc. test data (Lubrication, washer type etc):
Without lubrication
Proof load: 46kN

Bolt data

Dimension	M12	Length	-
Strength	80		
Surf.Treat.	Austenitic steel A4		
Head	WAP: 19mm		
Pitch(P)	1,75	D0	18
d2	10,863	dh	13,2

Misc. bolt data

Test results

	Fmax [kN]	Tmax (Nm)	µ total	µ1	µ2
1	33,9	303,9	0,48	0,44	0,54
2	32,6	294,0	0,40	0,35	0,46
3	41,7	329,2	0,44	0,54	0,31
4	41,5	332,9	0,30	0,26	0,34
5	38,1	291,4	0,33	0,24	0,44
6	44,3	323,0	0,43	0,33	0,57
7	40,4	338,5	0,50	0,46	0,57
8	36,9	311,3	0,57	0,54	0,61
9	39,7	321,7	0,43	0,40	0,46
10	42,4	351,1	0,36	0,33	0,39
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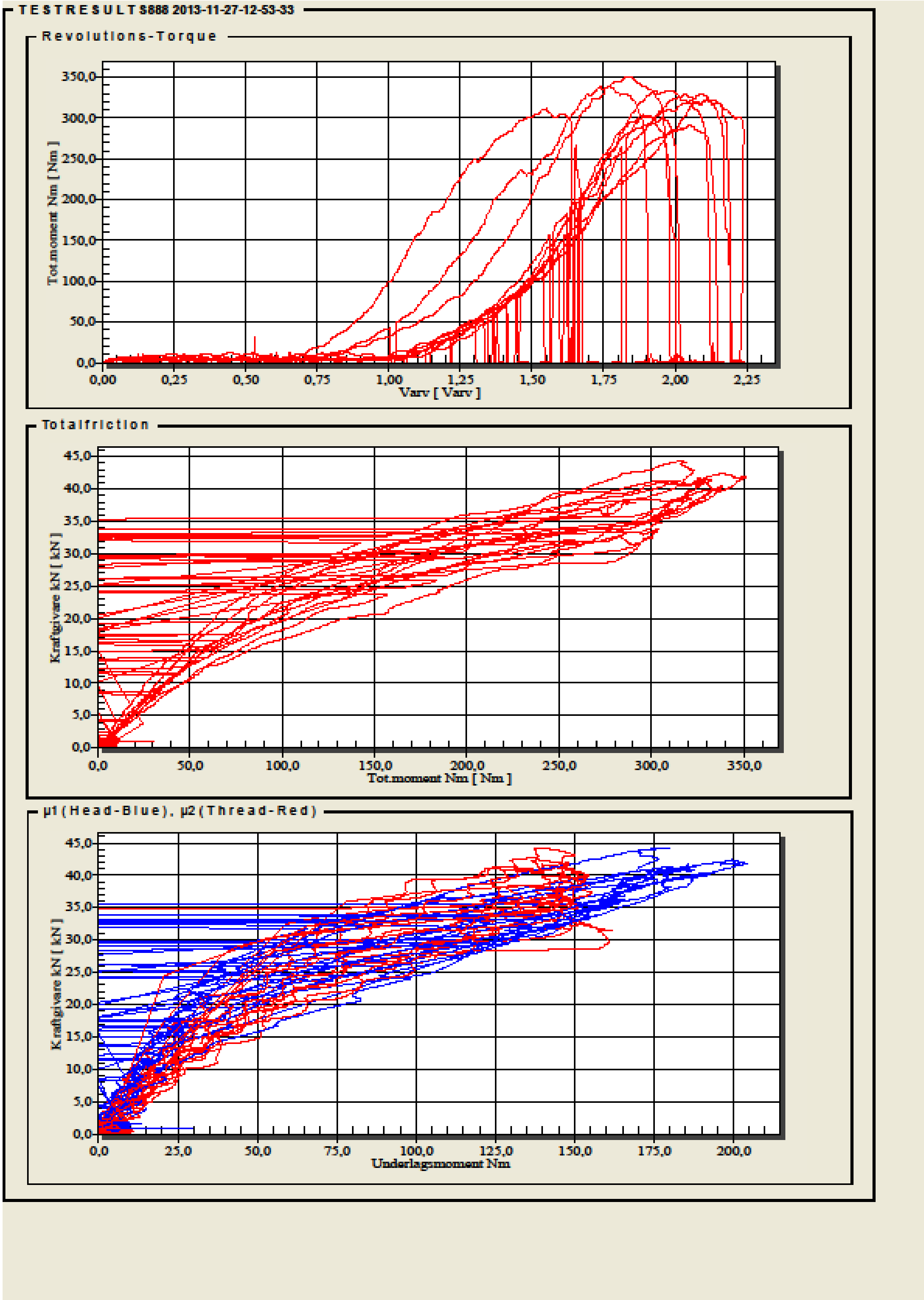
Statistics

Average µ: 0,42

Standard deviation µ: 0,08


TESTRESULTS888 2013-11-27-12-53-33
Revolutions-Torque
Tot.moment Nm [Nm]
Varv [Varv]
Totalfriction
Kraftgivare kN [kN]
Tot.moment Nm [Nm]
μ1(Head-Blue), μ2(Thread-Red)
Kraftgivare kN [kN]
Underlagsmoment Nm

A5.14 A4-80, G-rapid +

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

Customer

Customer

Bachelor - Frictiontest

Test data

Test type: Separate Head and Thread friction

Measure RPM: 10

Misc. test data (Lubrication, washer type etc)

Lubricated with G-rapid +
Proof load: 46kN

Bolt data

Dimension	M12	Length	-
Strength	80		
Surf.Treat.	Austenitic steel A4		
Head	WAP: 19mm		
Pitch(P)	1,75	D0	18
d2	10,863	dh	13,2

Misc. bolt data

Test results

	Fmax [kN]	Tmax (Nm)	μ total	μ1	μ2
1	47,9	104,5	0,13	0,10	0,16
2	49,2	116,0	0,17	0,11	0,24
3	50,5	81,4	0,09	0,09	0,09
4	48,3	99,2	0,11	0,08	0,15
5	48,7	75,1	0,09	0,09	0,09
6	48,2	77,8	0,09	0,11	0,07
7	48,4	116,7	0,12	0,12	0,13
8	48,5	78,6	0,09	0,10	0,07
9	48,5	81,5	0,09	0,12	0,06
10	50,3	82,9	0,10	0,12	0,06
11	47,4	88,7	0,11	0,10	0,13
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13					
14					
15					
16					
17					
18					
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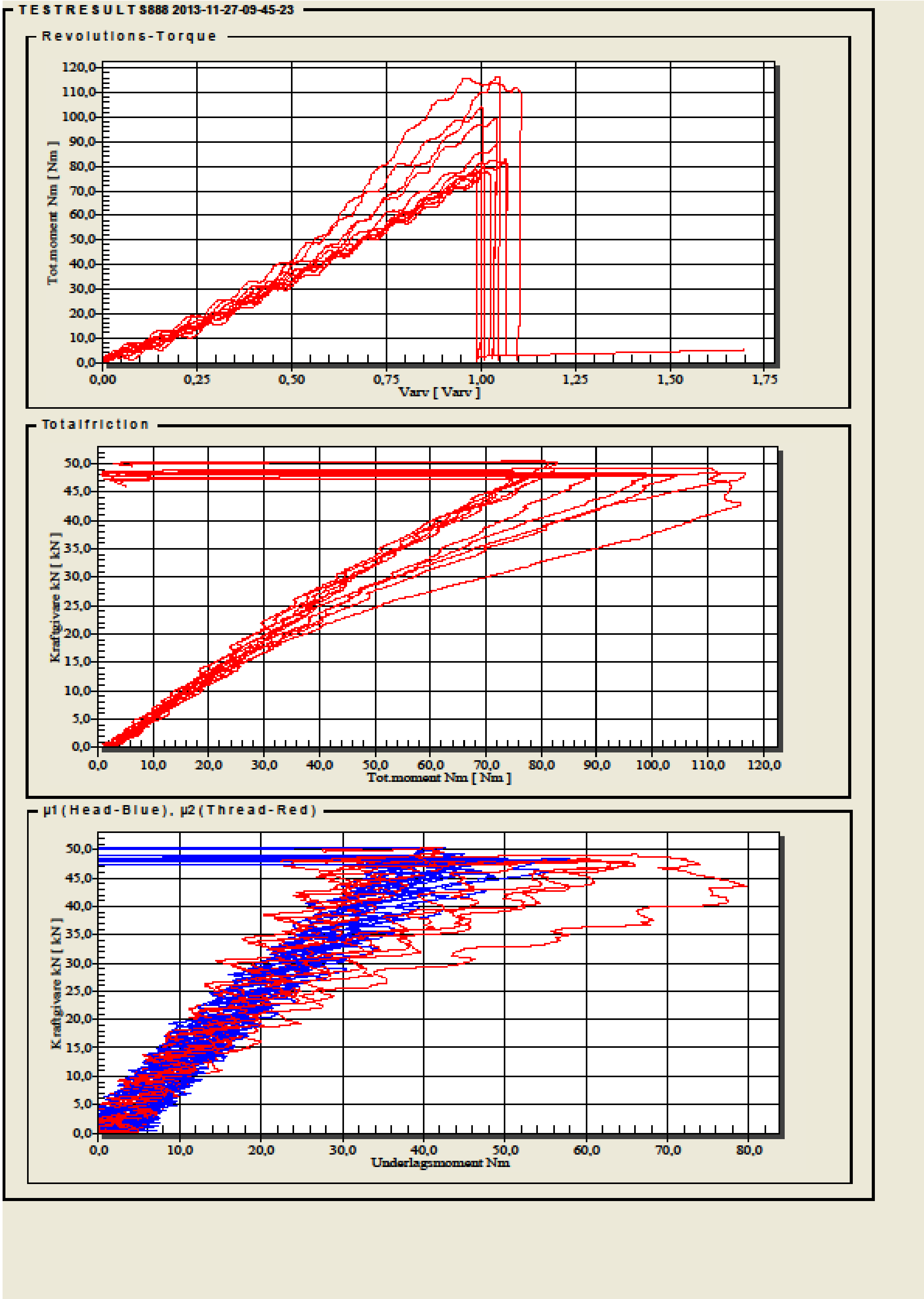
Statistics

Average μ: 0,11

Standard deviation μ: 0,02


TESTRESULTS888 2013-11-27-09-45-23
Revolutions-Torque
Tot.moment Nm [Nm]
Varv [Varv]
Totalfriction
Kraftgivare kN [kN]
Tot.moment Nm [Nm]
µ1(Head-Blue), µ2(Thread-Red)
Kraftgivare kN [kN]
Underlagsmoment Nm

A5.15 A4-80, Molykote 1000

T E S T R E S U L T S 2013-11-27-08-59-06

Customer

Customer: Bachelor - frictiontest

Test data

Test type: Separate Head and Thread friction

Measure RPM: 10

Misc. test data (Lubrication, washer type etc):
Lubricated with Molykote 1000
Proof load: 46kN

Bolt data

Dimension	M12	Length	-
Strength	80		
Surf.Treat.	Austenitic steel A4		
Head	WAP: 19mm		
Pitch(P)	1,75	D0	18
d2	10,863	dh	13,2

Misc. bolt data

Test results

	Fmax [kN]	Tmax (Nm)	μ total	μ1	μ2
1	49,0	167,7	0,21	0,16	0,27
2	49,8	174,9	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
5	51,0	139,0	0,16	0,14	0,17
6	49,3	171,9	0,18	0,18	0,18
7	49,6	135,5	0,19	0,14	0,24
8	49,7	146,6	0,15	0,16	0,14
9	49,3	148,7	0,16	0,15	0,16
10	49,1	140,9	0,18	0,20	0,16
11	48,2	116,9	0,15	0,15	0,15
12	49,6	110,2	0,13	0,15	0,11
13	49,9	165,4	0,20	0,22	0,17
14	48,6	136,2	0,16	0,18	0,13
15	49,2	122,4	0,14	0,14	0,14
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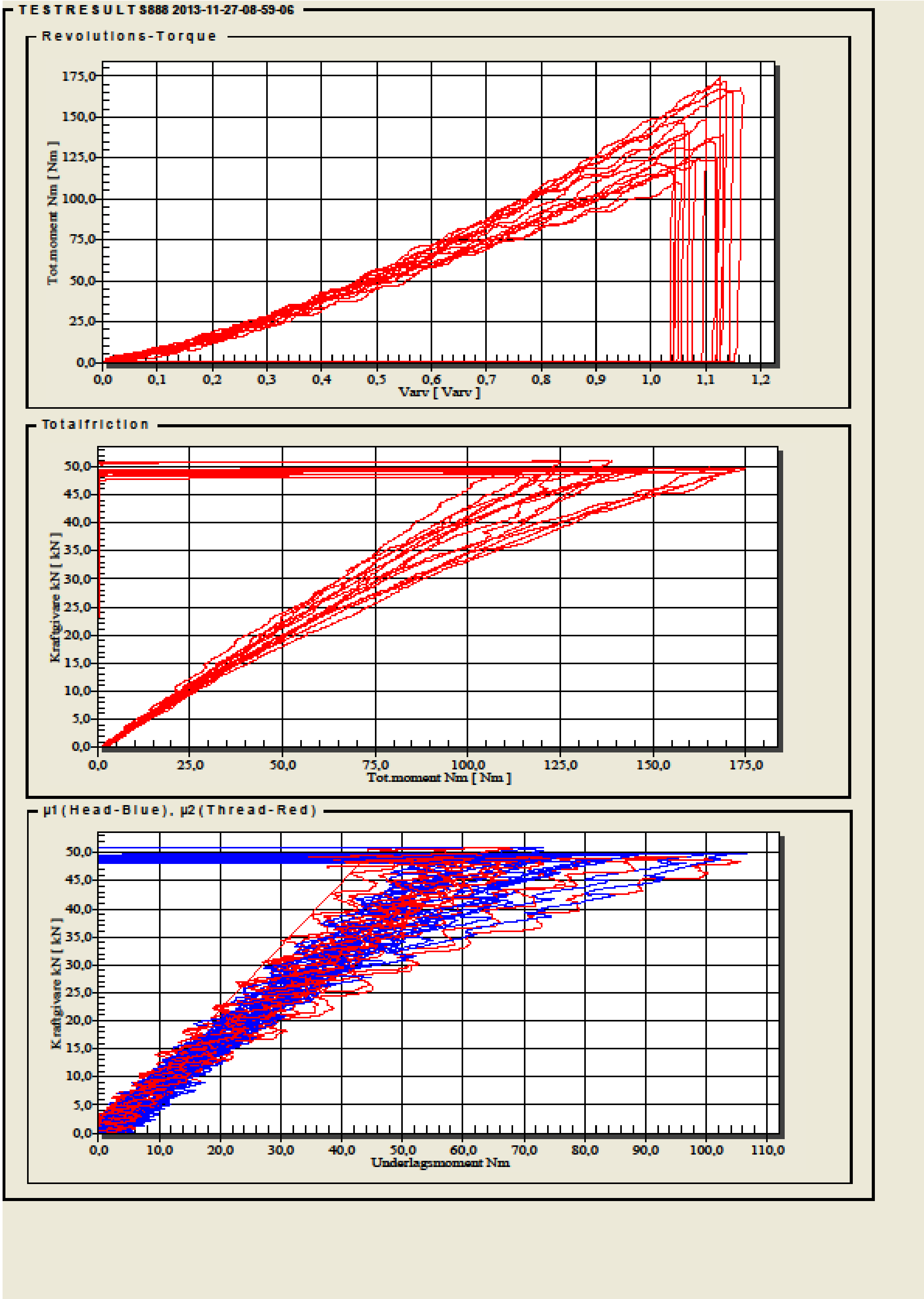
Statistics

Average μ: 0,17

Standard deviation μ: 0,02


TESTRESULTS888 2013-11-27-08-59-06
Revolutions-Torque
Tot.moment Nm [Nm]
Varv [Varv]
Totalfriction
Kraftgivare kN [kN]
Tot.moment Nm [Nm]
μ1(Head-Blue), μ2(Thread-Red)
Kraftgivare kN [kN]
Underlagsmoment Nm

A5.16 A4-80, Gleitmo 605

TESTRESULTS 2013-11-27-13-33-40

Customer

Customer: Bachelor - Frictionstest

Test data

Test type: Separate Head and Thread friction

Measure RPM: 10

Misc. test data (Lubrication, washer type etc):
Lubricated with Gleitmo 605 1:5
Proof load: 46kN

Bolt data

Dimension	M12	Length	-
Strength	80		
Surf.Treat.	Austenitic steel A4		
Head	WAP: 19mm		
Pitch(P)	1,75	D0	18
d2	10,863	dh	13,2

Misc. bolt data

Test results

	Fmax [kN]	Tmax (Nm)	µ total	µ1	µ2
1	48,7	286,5	0,42	0,45	0,38
2	48,7	301,6	0,37	0,39	0,34
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
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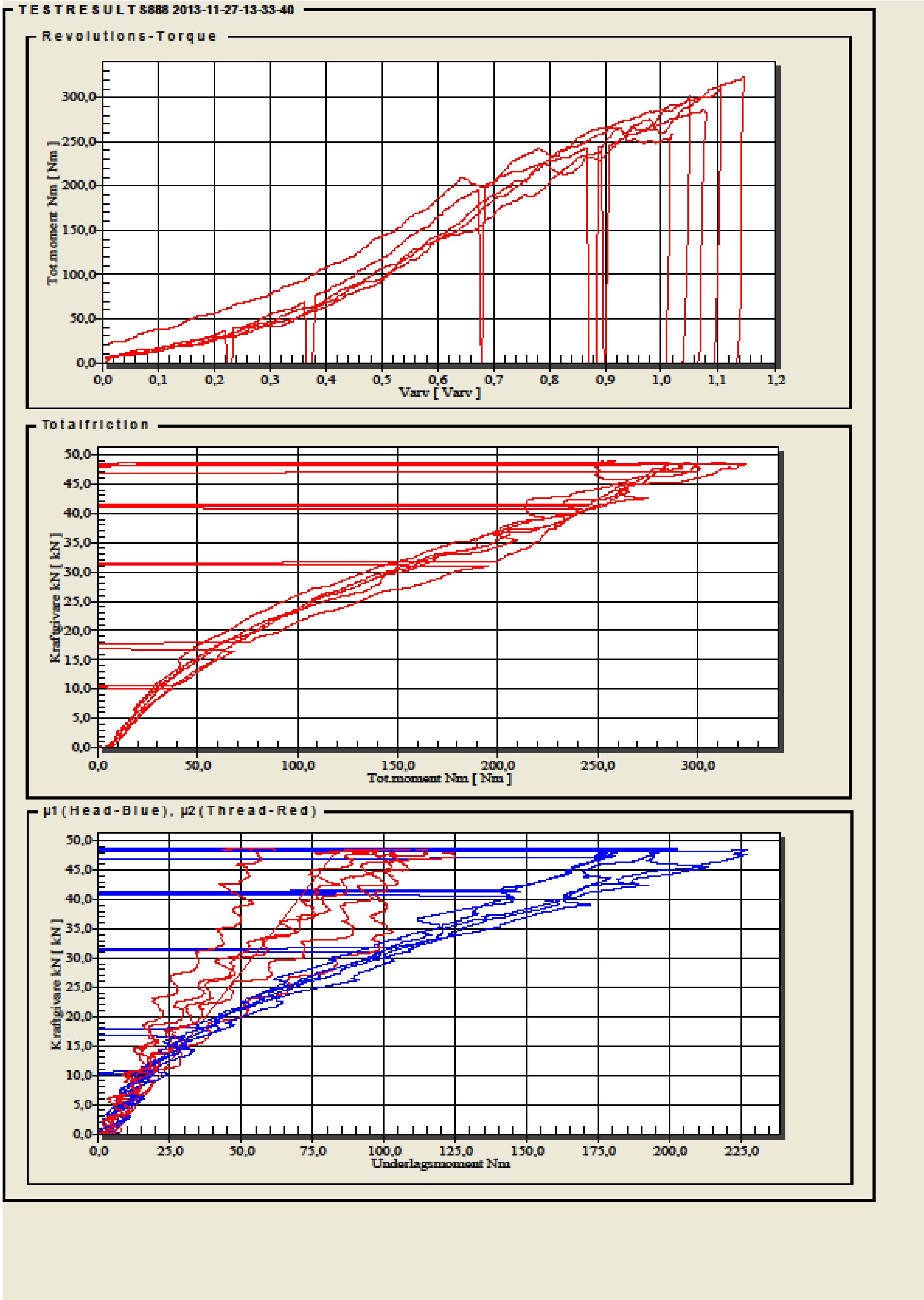
Statistics

Average µ: 0,38

Standard deviation µ: 0,02


TESTRESULT S888 2013-11-27-13-33-40
Revolutions-Torque
Tot.moment Nm [Nm]
0,0 50,0 100,0 150,0 200,0 250,0 300,0
0,0 0,1 0,2 0,3 0,4 0,5 0,6 0,7 0,8 0,9 1,0 1,1 1,2
Varv [Varv]
Totalfriction
Kraftgivare kN [kN]
0,0 5,0 10,0 15,0 20,0 25,0 30,0 35,0 40,0 45,0 50,0
0,0 50,0 100,0 150,0 200,0 250,0 300,0
Tot.moment Nm [Nm]
µ1(Head-Blue), µ2(Thread-Red)
Kraftgivare kN [kN]
0,0 5,0 10,0 15,0 20,0 25,0 30,0 35,0 40,0 45,0 50,0
0,0 25,0 50,0 75,0 100,0 125,0 150,0 175,0 200,0 225,0
Underlagsmoment Nm

A5.17 Zinc Flake, no lubrication

T E S T R E S U L T S 2013-11-27-12-26-45

Customer

Customer

Bachelor - Frictiontest

Test data

Test type: Separate Head and Thread friction

Measure RPM: 10

Misc. test data (Lubrication, washer type etc)

Without lubrication
Proof load: 48,9kN

Bolt data

Dimension	M12	Length	-
Strength	8		
Surf.Treat.	Zinc Flake		
Head	WAP: 18mm		
Pitch(P)	1,75	D0	17,25
d2	10,863	dh	13,2

Misc. bolt data

Test results

	Fmax [kN]	Tmax (Nm)	µ total	µ1	µ2
1	49,7	81,3	0,11	0,15	0,06
2	53,7	82,5	0,10	0,12	0,08
3	53,4	84,3	0,10	0,11	0,09
4	52,5	78,9	0,10	0,13	0,07
5	53,2	83,3	0,10	0,13	0,07
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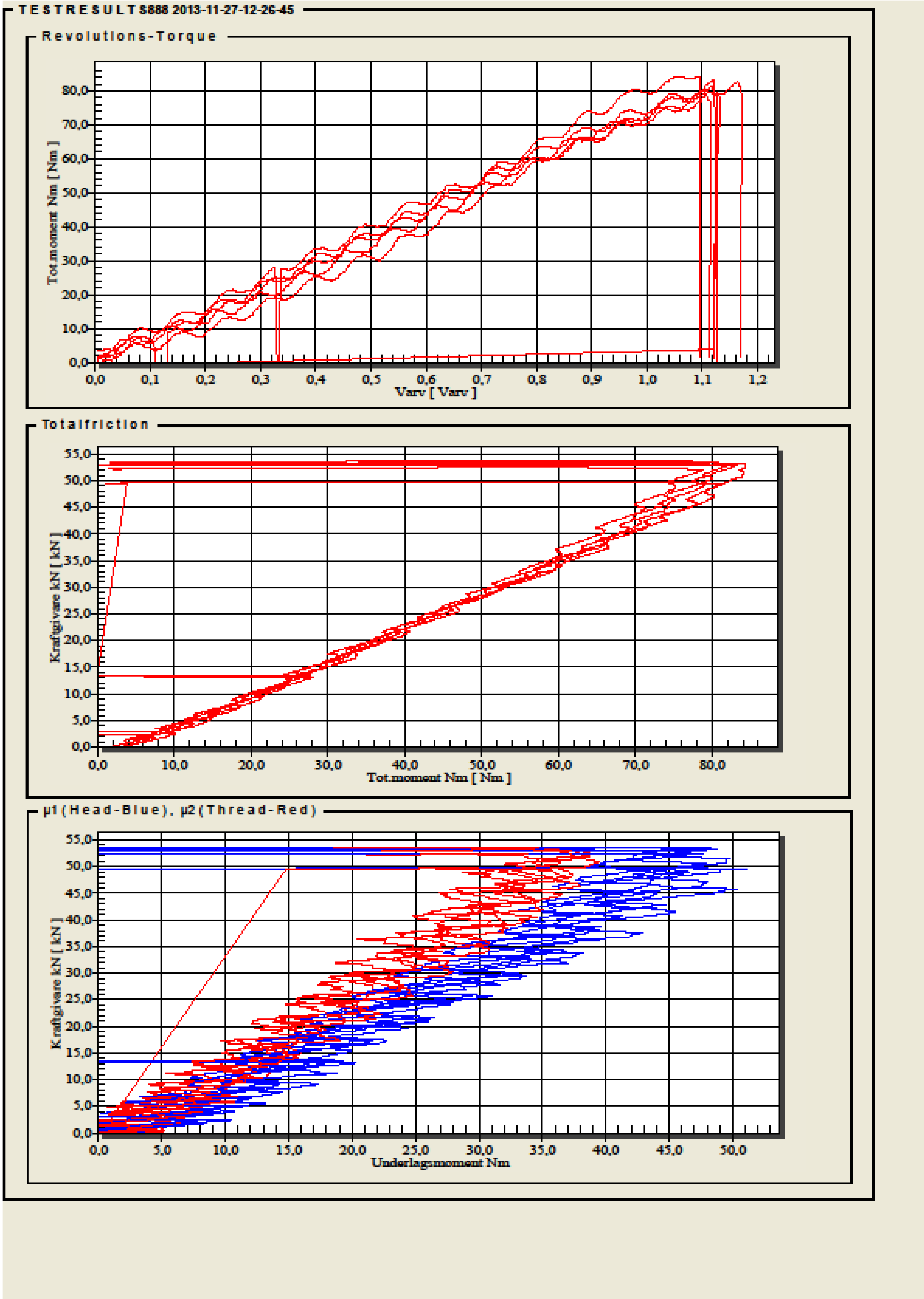
Statistics

Average µ: 0,10

Standard deviation µ: 0,00


TESTRESULT S888 2013-11-27-12-26-45
Revolutions-Torque
Tot.moment Nm [Nm]
Varv [Varv]
Totalfriction
Kraftgivare kN [kN]
Tot.moment Nm [Nm]
µ1(Head-Blue), µ2(Thread-Red)
Kraftgivare kN [kN]
Underlagsmoment Nm

A5.18 Zinc Flake, G-Rapid +

T E S T R E S U L T S 2013-11-27-14-06-58

Customer

Customer: Bachelor - frictiontest

Test data

Test type: Separate Head and Thread friction

Measure RPM: 10

Misc. test data (Lubrication, washer type etc):
Lubricated with G-Rapid +
Proof load: 48,9kN

Bolt data

Dimension	M12	Length	-
Strength	8		
Surf.Treat.	Zinc Flake		
Head	WAP: 18mm		
Pitch(P)	1,75	D0	17,25
d2	10,863	dh	13,2

Misc. bolt data

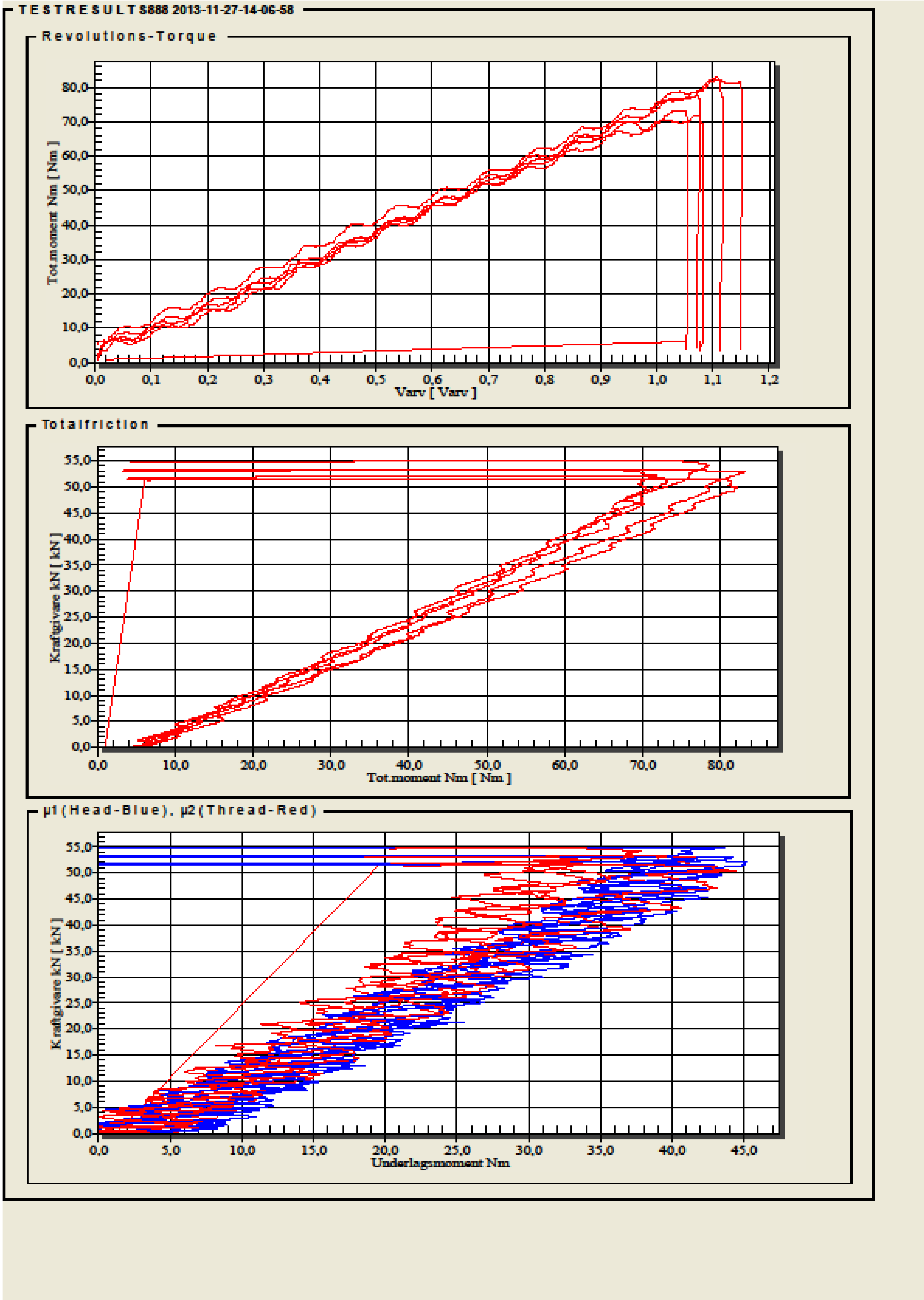
Test results

	Fmax [kN]	Tmax (Nm)	µ total	µ1	µ2
1	52,0	73,2	0,09	0,10	0,07
2	53,3	83,2	0,10	0,11	0,09
3	53,2	71,9	0,09	0,12	0,05
4	55,0	78,5	0,09	0,11	0,06
5	51,6	82,2	0,10	0,11	0,10
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					

Statistics

Average µ: 0,09

Standard deviation µ: 0,01


TESTRESULTS888 2013-11-27-14-06-58
Revolutions-Torque
Tot.moment Nm [Nm]
Varv [Varv]
Totalfriction
Kraftgivare kN [kN]
Tot.moment Nm [Nm]
μ1(Head-Blue), μ2(Thread-Red)
Kraftgivare kN [kN]
Underlagsmoment Nm

A5.19 Zinc Flake, Molykote 1000

T E S T R E S U L T S 2013-11-27-14-22-31

Customer

Customer

Bachelor - Frictiontest

Test data

Test type: Separate Head and Thread friction

Measure RPM: 10

Misc. test data (Lubrication, washer type etc)

Lubricated with Molykote 1000
Proof load: 48,9kN

Bolt data

Dimension	M12	Length	-
Strength	8		
Surf.Treat.	Zinc Flake		
Head	WAP: 18mm		
Pitch(P)	1,75	D0	17,25
d2	10,863	dh	13,2

Misc. bolt data

Test results

	Fmax [kN]	Tmax (Nm)	µ total	µ1	µ2
1	54,4	85,2	0,10	0,12	0,07
2	54,5	86,6	0,10	0,13	0,06
3	53,3	79,6	0,10	0,12	0,08
4	50,7	76,9	0,09	0,13	0,05
5	53,7	87,8	0,11	0,14	0,07
6					
7					
8					
9					
10					
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16					
17					
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19					
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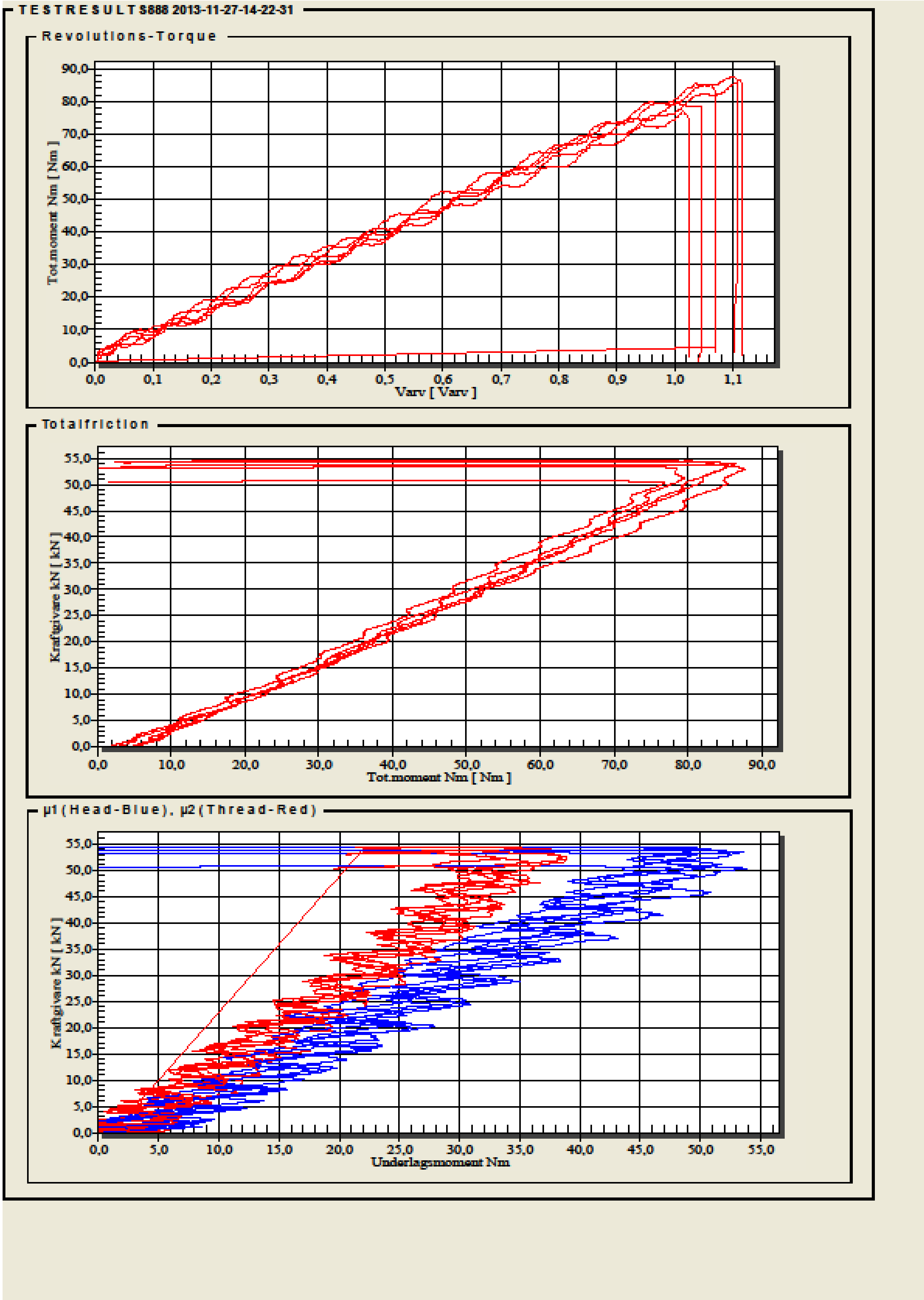
25					
26					
27					
28					
29					
30					

Statistics

Average µ: 0,10

Standard deviation µ: 0,01


TESTRESULTS888 2013-11-27-14-22-31
Revolutions-Torque
Tot.moment Nm [Nm]
Varv [Varv]
Totalfriction
Kraftgivare kN [kN]
Tot.moment Nm [Nm]
μ1(Head-Blue), μ2(Thread-Red)
Kraftgivare kN [kN]
Underlagsmoment Nm

A6 Appendix 6 – Tensile strength test

TESTRESULTAT 2013-12-16-14-19-43

Kund

Jacob Mortensen

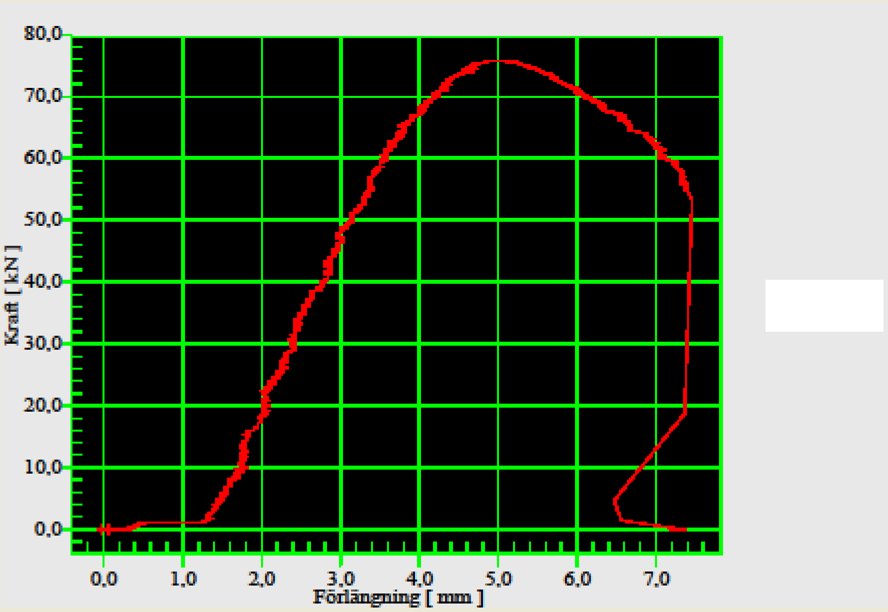
Skruvdata

Skruv	ISO4014/DIN931
Dimension	M12
Längd	80
Stigning (P)	1,75
Material	ISO898-1/ISO3506-1
Hållf.klass	8.8/A4-80

1.Ubehandlet 2.Elzinc 3.Varmzink 4.Rustfri
5.Zink flake

Uppmätta värden

	Sträckgräns (kN)	Brottgräns (kN)	Brott förlängning (mm)
1		78,8	
2		78,6	
3		74,2	
4		82,5	
5		75,8	
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
Max		82,5	
Medel		78,0	
Min		74,2	



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