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Date:	**Our reference**:	**Your reference**:
2022-11-29	1400521-9/Nst	-

Report: Assessment of a New Bolting System VIBRALOCK®

Dear Mr Nærland

Per your order, we have assessed your new bolt nut concept VIBRALOCK® regarding compliance with ISO 16130:2015.

1. Executive summary

1.1 Introduction

Bondura Technology AS has developed a nut-locking system named VIBRALOCK® for use in wind turbines and other industries. The objective of the test is to prove that the VIBRALOCK® system can prevent loosening of the nut and retain a much higher clamp load during operation compared to regular bolted systems, while still being easy to disassemble with the same torque and tension tool used for installation.
The bolt system is tested at alternating transverse loading to determine the resistance against loosening and loss of preload. Testing is performed comparing VIBRALOCK® with HV structural bolting assemblies using defined preloads. Strain gauges is mounted on the shank of the bolts to measure the tension force during testing.

The test procedure was developed by DNV AS, Oil & Gas, Laboratory & Testing – Oslo in accordance with ISO 16130:2015 as a Junker vibration test. Location of test is at the University of Stavanger, Norway.

1.2 Test Scope

The test jig is designed to test bolts of grade 10.9 in sizes M30x3.5 and M42x4.5 with a clamping length of 4 times the diameter. The test is defined by ISO 16130:2015 and the test equipment follow the requirements laid out by this standard. All parts of the bolt assemblies are hot dip galvanized. Preload of the bolts is achieved by tensioning of the shank. Strain gauges monitor the preload of the bolts, and displacement transducers monitor how much transverse movement was introduced to the surface plates where the bolted assemblies are clamped. The 250 kN test machine is running by amplitude control to a pre-set value for each test, and continuously logging the transverse force needed to achieve the amplitude.
ISO 16130:2015 define the following ratings of self-locking behaviour for the Junker vibration test:

Rating	Explanation	Relative clamp force loss
1	Good self-locking behaviour	0% - 15%
2	Acceptable loss of clamp force	15% - 60%
3	Poor self-locking behaviour	60% - 100%

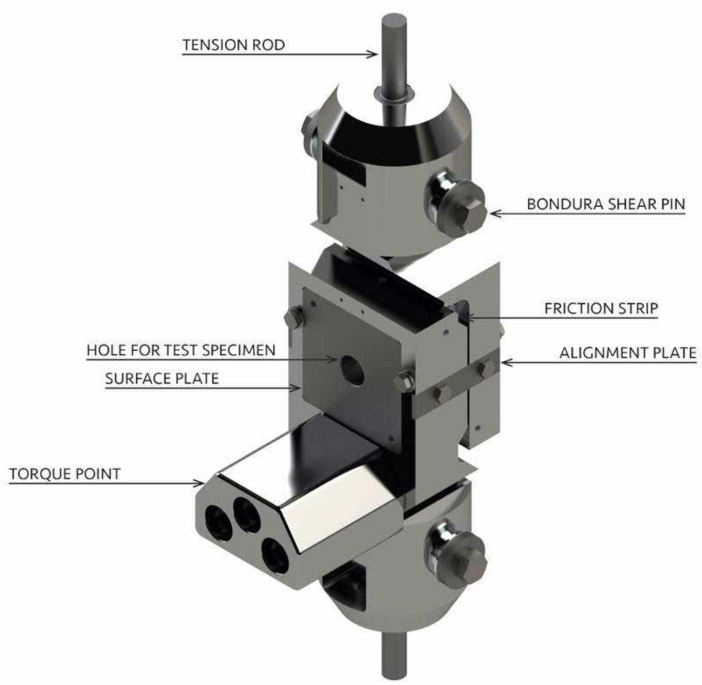
2. Testing

2.1 Setup

The machine used for testing is located at the University of Stavanger and is a fatigue testing machine that can achieve the load, amplitude and frequency needed for the test.
The load jig is designed for this scenario specifically with two main structure plates where one is moving by connection to the hydraulic cylinder while the other is stationary.
The jig is connected to the machine by a tension rod and pivot pin connection on the top and bottom. A PTFE gliding plate is located between the two structure plates to reduce friction and provide a smooth and even movement of the jig.
Replaceable surface plates are used under the bolt head and the nut to ensure the same surface conditions for each test. Alignment plates were used for the installation of bolts to centre the test samples.
Molykote® G-Rapid Plus are used as thread and assembly paste to maintain a consistent friction coefficient between the following surfaces for the duration of the test:

- Main (large) thread on bolt
- Lock (small) thread on bolt (VIBRALOCK®)
- Bearing face of main nut
- Conical contact surface between main and lock nut (VIBRALOCK®)

Test Equipment:



- MTS Series 809 Axial/Torsional Test Systems – Model 319.25
- MTS FlexTest 40 Controller & Series 793 Software
- Transverse Load Jig
- BLACKIRON 1000 kN Hydraulic Load Cell
- BLACKIRON Bridge for HV & VL
- BLACKIRON Conversion Kit M30 & M42
- BLACKIRON Electric Pump 1500 bar & 5 mtr hose
- TORQLITE IU-1XL with 50 mm head
- TORQLITE IU-3XL with 70 mm head
- TORQLITE Electric Pump 700 bar & 4,5 mtr twin hose

Measurement Equipment:

- HBM QuantumX MX440B & MX1615B with Catman AP software
- HBM WA-T Inductive Displacement Transducer (2 pcs.)
- Strain Gauge Quarter Bridge (2 pcs. per bolt)
- Strain Gauge Full Bridge (2 pcs. per bolt)
- PT100 Temperature Sensor (1 pc.)
- Actuator Force Load Cell (1 pc.)
- Actuator Displacement Transducer (1 pc.)

Test Samples:

- Bolt/nut Assembly EN 14399-4 – HV – M30 x 185 x 74 – 10.9/10 – tZn – K1
- Bolt/nut Assembly EN 14399-4 – HV – M42 x 260 x 135 – 10.9/10 – tZn – K1
- VIBRALOCK® M30 x 195 x 84 – 10.9/10 – tZn
- VIBRALOCK® M42 x 275 x 134 – 10.9/10 – tZn

2.2 Instrumentation

Description	Instrument type	Comment
Relative movement	Two displacement transducers on structural plate elements	Zero-point set before every test
Clamp force	Two strain gauges on opposite sides of bolt shank	Quarter bridge configuration Full bridge configuration
Temperature	Temperature sensor located on bolt head	Temperature differences is compensated in Catman software during testing for quarter bridge SG
Actuator force	Load cell	System control
Actuator displacement	Displacement transducer	System control

The actuator force and displacement are logged by the MTS test machine control unit and computer. Data from the strain gauges and displacement transducers is logged by HBM QuantumX data acquisition devices via Catman AP. Most bolts are instrumented with two quarter bridge strain gauges and some are with a full bridge strain gauge configuration. The test frequency of amplitude was 1 Hz with data logging of 100 Hz.
The effects of temperature change in strain value are corrected with a polynomial specified in the strain gauge data sheet for the quarter bridge configuration.

2.3 Test Program

A tension tool is used to achieve the preload specified.
A few test runs were necessary in the beginning to determine the correct amplitude to use for testing where the reference bolts lose at least 90% clamp load between 200-400 cycles.
Reference tests of HV bolts are repeated 3 times with the determined amplitude.
VIBRALOCK® bolts is tested for verification of the system with a minimum of 3000 cycles for each test samples and repeated 3 times.

Size	Clamped thickness [mm]	Preload [kN]	Hole diameter [mm]	Torque value lock nut [Nm]	Expected relative movement [mm]
M30x3.5	120	353	33	260	1,02
M42x4.5	168	706	45	850	1,46

2.4 Test Monitoring and Logging

The following data is monitored in real-time and logged at a frequency of 100 Hz:

- Clamp load
- Relative displacement
- Temperature

The following peak-valley data is logged for each cycle:

- Actuator force
- Actuator displacement

The following data is recorded per test run:

- Test ID
- Strain Gauge ID
- Date performed
- Zero value for strain gauges
- Initial clamp force
- Machine amplitude
- LVDT amplitude
- Cycles run
- Final clamp force
- Clamp loss (calculated)

Video recordings of the tests with markings to show relative angular rotation of the nut are also available.

2.5 Test Result

Test ID	Type	Diameter	Start load [kN]	Amplitude	Cycles Run	Final load [kN]	Clamp loss
C02.1	HV	30	348,6	+0,85/-0,80	389	22	93,69 %
C04.1	HV	30	344,2	+0,90/-0,90	399	34	90,12 %
C06.1	HV	30	344,3	+0,90/-0,85	398	28,5	91,72 %
C08.1	HV	30	354,7	+0,90/-0,85	324	34	90,41 %
C03.1	VL	30	341,4	+0,90/-0,85	3017	317	7,15 %
C05.1	VL	30	349,3	+0,90/-0,85	3038	331	5,24 %
C09.1	VL	30	350,2	+0,90/-0,85	3021	322,7	7,85 %
T03.0	VL	30	329,6	+0,80/-0,75	3114	317	3,82 %
T08.0	VL	30	322,9	+0,95/-1,00	3061	305	5,54 %
T09.0	VL	30	353,8	+1,00/-0,95	3053	330	6,73 %
T10.0	VL	30	355,3	+1,00/-0,95	3076	330	7,12 %
C11.1	HV	42	698,7	+1,30/-1,30	334	50	92,84 %
C15.1	HV	42	708,3	+1,60/-1,50	204	61	91,39 %
C16.1	HV	42	701,0	+1,50/-1,30	269	56	92,01 %
C17.1	VL	42	692,4	+1,45/-1,40	3030	639	7,71 %
C18.1	VL	42	713,2	+1,50/-1,30	3035	673	5,64 %
C19.1	VL	42	690,2	+1,40/-1,40	3055	629	8,87 %
T23.0	VL	42	725,6	+1,00/-1,00	3031	693,9	4,37 %

3. List of assessed documents

List of reports

Document No.	Revision	Title
689477 - M30x195-84 Vibralock	02-09-2021	Test Report
689479 - M42x275-134 - Vibralock	01-09-2021	Test Report
689480 - M30x185 - HV	02-09-2021	Test Report
689481 - M42x260 - HV	02-09-2021	Test Report
1030185550_94900_689480_markDOKKA10.9HV0411_24pcs	06-09-2021	Certificate

Document No.	Revision	Title
1030195550_94900_689477_markDF10.9040X_16pcs	06-09-2021	Certificate
1042260550_94900_689481_markDOKKA10.9HV0412_24pcs	06-09-2021	Certificate
1042275550_94900_689479_markDF10.90410_16pcs	06-09-2021	Certificate
Clamp Force Settings acc. to VDI 2230	18-07-2022	Calculation
VIBRALOCK® Report from Laboratory Test	17-01-2022	Document No. 21-01405-REP-001
VIBRALOCK Test Summary	--	Excel File
Statistical interpretation of data - One sided interval	--	Excel File, received with e-mail dt. 28-09-2022 from Mr Enok Nærland of Bondura

List of drawings:

Document No.	Revision	Title
014381	A	Drawing
014378	A	Drawing
014779	A	Drawing
014380	A	Drawing
014377	A	Drawing
014374	A	Drawing
014783	A	Drawing

Document No.	Revision	Title
014376	A	Drawing
015428	02-10-2021	Drawing
014771	22-03-2021	Drawing
014904	07-05-2021	Drawing
015109	15-06-2021	Drawing

List of specifications/manuals/instructions:

Document No.	Revision	Title
2020-3235	1	Bondura Bolt Locking Test Procedure by DNV GL Norway
Test explanation supplement to procedure	---	Document

List of documents taken for information only:

Document No.	Revision	Title
VIBRALOCK Design Requirements	05	Design Requirements

4. Remarks

Proof of Calibration of all used tools and gauges has been provided and is filed at DNV.

- Videos showing
  - Change of bolt procedure
  - Lubrication and tension of HV bolt
  - Lubrication, tension, and torque of VIBRALOCK® bolt
  - The bolts subjected to test load

  have been submitted and are filed at DNV.
- Photos of the test rig, tools and gauges have been submitted and are filed at DNV.
- Two tests were remotely witnessed by DNV on the 11-08-2022.
- For each test, new bolt, nut, lock nut and surface plates were used.
- The statistical interpretation of data was carried out according to ISO 16269-6:2014.

5. Conclusion

Testing shows that standard HV bolts experience uniform loss of preload over the duration of the test with steady loosening of the nut. With the amplitudes specified, a loss of 90% is obtained between 200-400 cycles before the test is stopped to prevent surface damage to the test equipment.

For verification of the VIBRALOCK® system, the test was performed with similar amplitude and run for at least 3000 cycles to show the difference between the systems.

A loss of preload from 3,82% to 8,87% was measured by instrumentation after 3000 cycles.

No turning of the nut was detected on any of the VIBRALOCK® bolts for the duration of the test. In comparison, for the HV system, the nut started to turn almost immediately after starting the test. This was verified by video and markings on all parts.

All bolts were disassembled with the same tools used for installation, proving the simple removal process of the VIBRALOCK® system.

Based on the above listed documentation we herewith confirm

- That the tests were carried out according to ISO 16130:2015.
- That on the confidence level of 0,95 at least 95% of the VIBRALOCK® M30 bolted joints the clamp loss will remain below 11% when subjected to transverse loading.
- That on the confidence level of 0,95 at least 95% of the VIBRALOCK® M42 bolted joints the clamp loss will remain below 17% when subjected to transverse loading.

In conclusion, the VIBRALOCK® shows a good resilience against loosening of the nut and an acceptable resilience against loss of preload under transverse loading conditions while still being easy to remove if needed.

We thank you for the good cooperation and remain

Yours faithfully,

DNV Renewables Certification GmbH

i. A. Bernd Niederstucke   i. A. Martin Dyzmann