Beyond Junker: A paradigm shift in validating and optimising bolted joints

By Morten Schiff, chief executive officer, Vibrationmaster

Validating and optimising bolted joint design delivers safety and performance improvements, alongside streamlining costs. There is now a powerful new vibration test methodology using controlled shear force loading. It is significantly more advanced than traditional – and flawed – displacement amplitude-driven Junker testing. This new approach enables users to test bolted joints for resistance to rotational self-loosening under real-world conditions.

Testing is essential, but existing validating bolted joint integrity tests are flawed

Fastener manufacturers, fastener distributors, and the design engineers within end-users, typically vibration test bolted joints to understand self-loosening behaviour and the performance of the locking elements intended to prevent rotational self-loosening. The results, traditionally generated by Junker testing, are extrapolated to underpin assumptions about how the resulting bolted joint will perform under operating conditions.

Although valuable, existing tests such as Junker's are flawed when used in this way. Junker testing is a powerful tool when comparing various fastener locking elements, such as lock nuts, wedge washers and chemical locking, to prevent self-loosening. The DIN and ISO standards are useful for product comparisons. But the Junker tests required by these engineering standards result in forced full displacement on the bolted joint from the outset. This is not what happens in real-world situations and not what bolted joints are designed for.

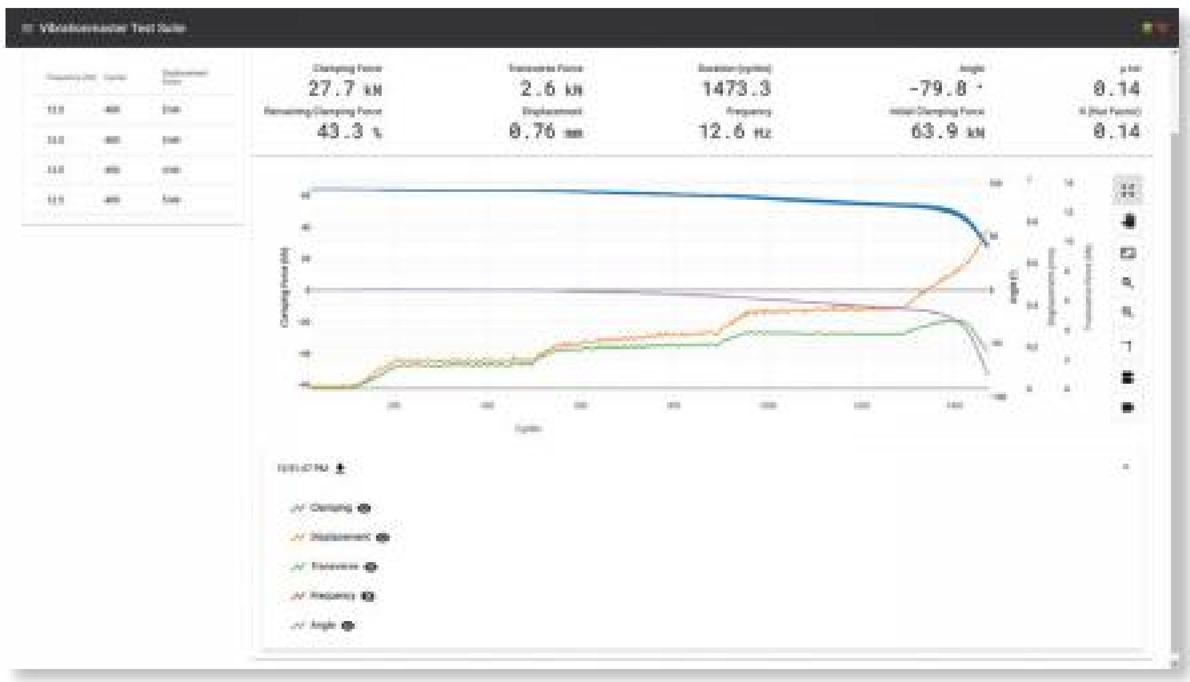

Figure 1: Junker test loosening curves demonstrate self-loosening behaviour, providing valuable data for fastener performance comparison but not bolted joint performance

There is another challenge. Existing equipment solutions test fasteners using fixture plates with roller bearings in between that do not have the same inner joint surface friction as the materials that are specified in the bolted joint design. As a result, they have completely different performance characteristics, such as friction coefficients. Roller bearings in existing Junker test machines mean the actual surface friction between the clamped parts is much lower than that of the real bolted joint design. Both these factors, forced full displacement and the use of roller bearings to ease the amplitude driven movement between the clamp surfaces, mean the bolted joint is not undergoing testing in anything like real-world conditions.

Rotational loosening theories and resulting standards require updating

The theory underpinning the existing widely used vibration tests has also advanced. In 1969, what was then ground-breaking research by Professor Gerhard Junker[1] showed that rotational self-loosening occurs when a transverse load is acting perpendicular to the bolt axis of a preloaded fastener connection. As a result, the conventional testing strategy for the last half-century has been to use Junker tests, and more recently measure the effectiveness of fastener locking elements against one of the three common standards: DIN 65151[2], DIN 25201[3] and ISO 16130[4]. ➔

Figure 2: Junker test fixture using roller bearings between clamped parts. Although ideal for comparing fastener locking element performance, the fixture materials have different inner joint surface friction characteristics than those specified in the bolted joint design

These standards require forced full displacement on the bolted joint from the outset. In real-world operating conditions, when a bolted joint is subjected to a shear force, it has been specifically designed not to result in slippage between the clamped parts. The very reason for the existence of a bolted joint is to maintain integrity. In real-world conditions, the transverse shear force load may, when it reaches a high enough magnitude, trigger limited microslip initially.

Only when the shear force increases to the point when it triggers slippage between the clamped parts does the displacement amplitude increase. The result is relative motion in the threads and rotational self-loosening starts. The relative motion cancels the grip caused by friction and generates an off-torque, which is proportional to the thread pitch and to the clamping force. If the friction under the nut or bolt bearing surface is overcome by the off-torque, the off-torque then rotates the nut or bolt, so it loosens, leading eventually to bolted joint failure.

Introducing closed-loop controlled transverse shear force vibration testing

Advances in bolted joint performance theory, and test equipment design, deliver a powerful new solution to check bolted joint integrity that overcomes the inherent flaws in Junker tests and the equipment currently used to conduct them. There are two key challenges to overcome: The forced full displacement amplitude driven Junker tests demand and the use of fixture plates with roller bearings reducing inner joint surface friction.

To overcome the first challenge, we do not create the test conditions that the DIN and ISO standards specify by applying full displacement amplitude from the outset. Instead, using innovative vibration testing technology, we apply a closed loop controlled transverse shear force to the bolted joint. If the joint has been designed correctly, this shear force will replicate the operating shear force and the joint will retain its integrity. However, when we increase the transverse shear force to the exact level where it triggers slippage between the clamped parts and increases the displacement amplitude, we know the shear force value at which the joint will fail.

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Figure 3a: Existing test solutions using roller bearings between the clamped parts reducing the inner surface friction

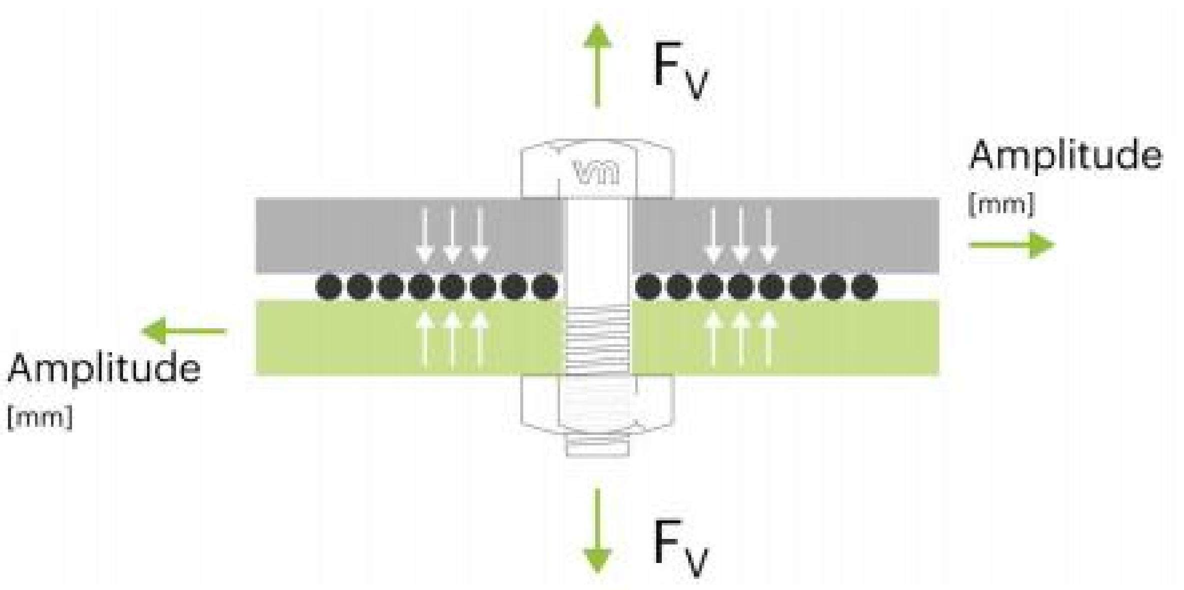
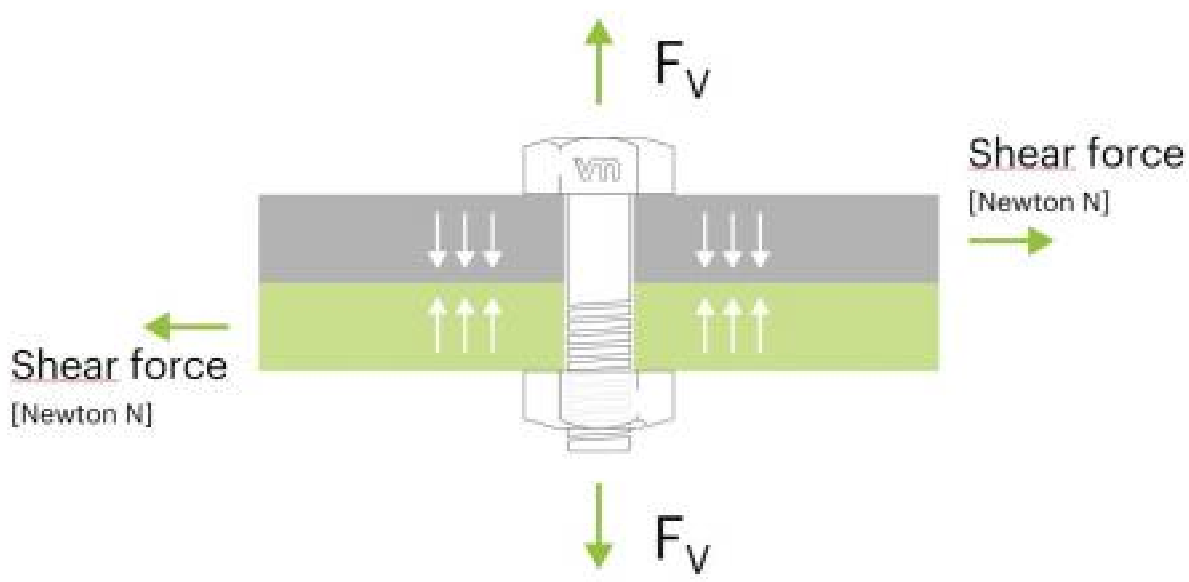


Figure 3b: New test fixture that uses the same materials as specified in the bolted joint design without the roller bearings reducing the inner joint surface friction.



There are two solutions to address the second challenge created by using fixture plates with roller bearings that have incorrect surface friction performance criteria:

- **Calculate a correction factor:** Create a fix that corrects the shear force applied by the test machine to correct the test conditions for the different material properties. Figure 3a shows that when we test a fastener using a conventional Junker test fixture, the roller bearings have a lower friction of, for example, 0.01. The joint we are testing would experience an operational shear force load of 3,700N with two steel-to-steel surfaces that have a friction of 0.20. When simulating operational stress, the test machine would not be using a force of 3,700N, but, instead, a force corrected with a factor based on the reduction of inner joint surface friction.
- **Replicate the actual bolted joint materials with direct contact between clamped parts:** Using a test fixture that incorporates the same materials as the bolted joint design and where the steel parts, or whatever material is in the design, are clamped directly together, as shown in Figure 3b. As a result, the friction will be exactly what is specified in the design and experienced under operating conditions.

When using the new test methodology, the transverse shear force as measured in Newtons [N] is the lead parameter while the displacement amplitude measured in millimetres [mm] is simply a result of the forces acting on the joint. This is how a bolted joint behaves under operating conditions.

The outcome is a dataset and analysis of bolted joint performance under specific operating conditions that the fastener design engineer can apply to refine the bolted joint integrity.

Figure 4: Vibration test equipment that can deliver closed-loop controlled transverse shear force and includes the inner joint surface friction correction factor and the option of using the same materials specified in the original bolted joint design clamped directly together.

Using test data to optimise safety factors and bolted joint design

Now we have a test that works. The closed loop transverse shear force test, incorporating the roller bearings and controlled shear force loading solution, can test real-life applications accurately and bolted joint performance under accurate simulated operating conditions.

The implications of this are significant – we can now determine a safety factor for the integrity of a bolted joint and, in turn, optimise the joint design.

If, for example, the operating transverse shear force on the bolted joint has been calculated by finite element analysis (FEA) to be 3,700N, we can test the joint using the correct materials or the roller bearing correction factor and deliver 3,700N. If there is no movement between the clamped parts, then the bolted joint has passed the test. Next, we can explore the bolted joint design's safety factor. Let's say we assume a safety factor of three and apply 11,100N. If the bolt continues to perform without the transverse shear force triggering slippage in the clamped parts, then we know we can either continue with a design that has a safety factor of three or, if the application does not require a safety factor of three, we can start optimising the joint design.

This new vibration test has two benefits. First, we can validate safety factors and establish whether the safety factor is proportionate for the application; and, second, we can optimise overdesigned bolted joint designs, leading to multiple additional benefits. There are many examples where machinery is subjected to extreme and out-of-scope stresses that require high safety factors. Construction plant and equipment is often used incorrectly, such as lifting loads that are too heavy or using a machine attachment for the wrong application. In this context, safety factors are much higher.

We know that many joints are over-designed, particularly in cars. They use bolt sizes and materials that are overrated for the specific application, resulting in unnecessary weight, size and cost. Perhaps we can use an M8 instead of an M10, or a different grade of material? If this bolted joint will feature in many units, this could result in a large cost saving. If many of these joints are used in the sub-assembly or product, this may mean a weight saving, which, in the case of a car design, could reduce emissions or could reduce space required because the joint has a smaller footprint.

Transforming bolted joint design through a new vibration testing approach

Previously, without building expensive and often unique one-time-use test rigs, engineers were unable to test how their bolted joint designs will perform under operating conditions, until the joints are prototyped or even in production. Also, testing for safety factors and joint optimisation had been a lengthy, complex and often expensive process.

Our unique vibration testing methodology and vibration test equipment enables all the stakeholders in the design of fasteners and bolted joints – from fastener manufacturers through fastener distributors to the design engineers within end-users – to benefit from greater certainty that their designs will perform as intended.

For further information about how our new closed-loop controlled transverse shear force vibration testing can assist with your fastener and bolted joint designs visit vibrationmaster.com +

References

1. *Junker G, New Criteria for Self-Loosening of Fasteners Under Vibration, Transactions of the Society of Automotive Engineers, Vol. 78, 1969, pp. 314-335, New York*
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