The Smart Flange Joint – Bolt Force Measurement with Foil Sensors

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Static flange joints heavily rely on the applied bolt force. A correct pretension guarantees a proper tension on the gasket and low leakage rates. On the other hand, a bad installation can lead to severe damages like sudden escape of aggressive chemicals which could endanger life of employees and would also harm the environment.

Since precision tools are expensive, flange joints are usually assembled with inaccurate torque wrenches. As measurement equipment is often not made for the rough industrial conditions, it is difficult to monitor bolts over their whole lifespan. That is why a loss of gasket tension can often only be anticipated through frequent maintenance.

To solve these problems, we are developing a new foil sensor. The foil sensor has a thickness that is measured in micrometres and is supposed to be applied within a washer under the bolt head. After successfully measuring the bolt force under laboratory conditions, we are confident to soon present a sensor for large scale industrial applications.

The sensors are manufactured at competitive costs and are not limited to the assembly processes. Instead, we hope to provide a sensor that enables the plant operators to monitor their flange joints over several years. Thus, we want to develop a warning system against certain irregularities like a drop in gasket tension etc. By collecting data and with the help of artificial intelligence we hope to gain further insights into industrial applications and to increase plant security while decreasing maintenance costs.

1 Introduction

Gaskets are very crucial parts of every plant. A gasket failure results in downtimes, high costs and sometimes even environmental pollution or endangerment of human life. Gasket failure is often not caused by a defect within the gasket itself. More frequently, gaskets fail due to an improper assembly (26 percent), an incorrect alignment (12 percent), because of a damaged flange (25 percent) or loose bolts (15 percent) [1-2].

To ensure an even compression of the gasket, the flange joint is usually assembled in several rounds with gradually increasing the tension [3]. Since the bolts are tightened clockwise, this procedure requires a lot of passes and time [4]. Various publications target this issue by trying to reduce the number of passes. One approach is to calculate the expected elastic crosstalk between the bolts in advance and assemble the flange joint in only one round. Nevertheless, this so-called *Elastic Interaction Coefficient Method* (EICM) is based on either experimental or FEA studies that must be conducted for each flange joint in advance [5].

Another problem lies in the tightening equipment. The fitter can assemble the flange joint with a simple and cheap torque wrench with an accuracy of less than ±20 percent. Alternatively, the fitter can use highly accurate equipment like hydraulic tightening tools at the price of higher assembly costs. Nevertheless, without measurement equipment like strain gauges or ultrasonic measurement of the bolt elongation it is tough to reach an accuracy under ±10 percent [6]. In special applications measurement equipment like load cells is used. Unfortunately, this equipment is expensive as well and it is not supposed to stay within the fastener after assembly since it usually cannot withstand the rough conditions during operation (temperature, etc.).

Following the assembly some gaskets incur a preload loss within the first hours and a retightening is necessary. Especially PTFE gaskets deform slowly over the whole life span due to creep relaxation. The loss of gasket stress can lead to a blow out and must be impeded. Fig. 1 shows the gasket stress of two PTFE gaskets over three years as an example. Due to great chemical resistance, the creep relaxation can be considered as the only ageing mechanism in PTFE gaskets [7].

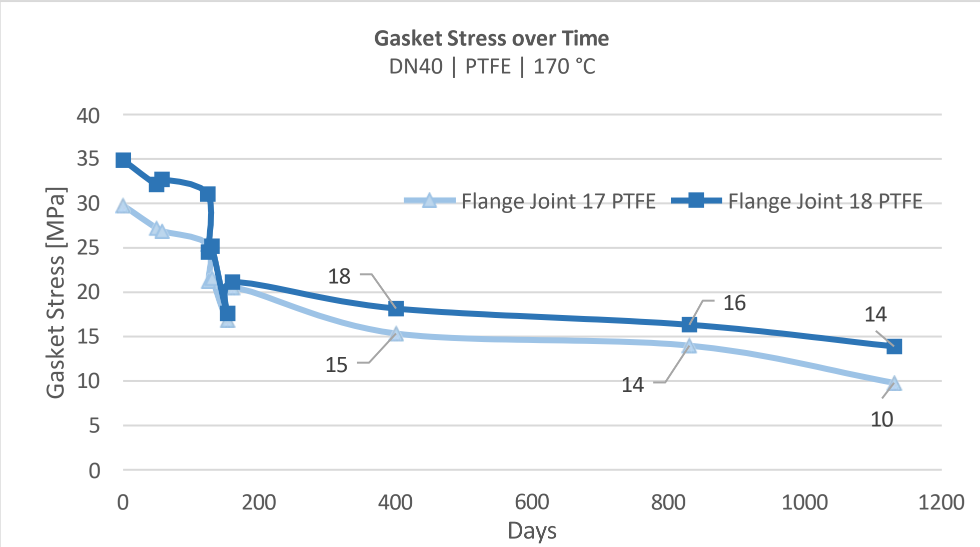

Figure 1: Long-term tests with PTFE gaskets

If it was possible to monitor the bolt force continuously during the assembly, gasket failure due to assembly errors could be prevented. Independent from the assembly tools used it would be possible to guarantee a uniform and accurate gasket stress. At the same time, it might open ways to accelerate the assembly process. By means of Artificial Intelligence (AI) and the live data of the bolt forces, it could be possible to determine the elastic crosstalk between bolts in real-time during the assembly. Alternating approaches like EICM with these measurements could make it possible to significantly reduce the number of passes and rounds and thus the assembly time.

After the assembly, a bolt monitoring technique could inform about the perfect time for retightening and during the gasket's life span any unusual drop in bolt forces could be detected. For gaskets whose aging is reflected in a drop of gasket stress and bolt force (i. e. PTFE gaskets), it would become possible to easily predict the remaining lifetime. As a result, maintenance intervals could be extended, and system downtimes would be reduced.

2 A Foil Sensor as the Solution

A new foil sensor that is placed inside a washer under the nut and the bolt head could bring the solution. Fig. 2 shows an early prototype of the washer and fig. 3 shows the current version of the foil sensor. It is noticeable that the sensor is divided into three parts. This enables us to monitor the alignment of the bolt itself and probably of the whole flange joint.

Figure 2: Washer with integrated foil sensor

In a first step we only want to develop an assembly sensor. Due to its competitive costs the sensor can remain inside the fastener after the assembly is completed. Even if the rough operating conditions damage the foil or influence the measurement values it is of no disadvantage. At this point we can already make the assembly process much safer and faster and offer a tool to monitor and document every flange joint.

Figure 3: Foil sensor with three pads for alignment measurements

In the second step we hope to improve our foil sensor in a way that it can also withstand higher temperatures up to 200 °C during plant operation. After the assembly the sensor would continue to measure the bolt forces and notify in case of any irregular event. By means of AI we aim to predict the remaining lifetime of the gasket. In addition to the bolt force, other measured variables are conceivable at a later step. Whether in the sensor itself or in the connected electronics – values such as temperature could also be included in the AI algorithms.

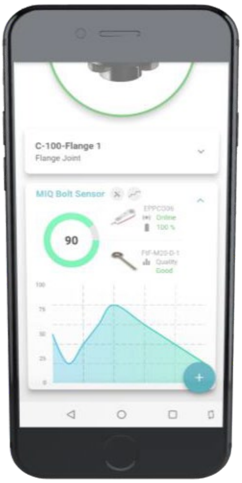

Figure 4: App with connected Bolt Sensor

Currently, the measurement data is collected with an electronic device that connects to a smartphone application via BLE. The app (fig. 4) shows the bolt force and leads the fitter through the complete assembly process. Depending on the number of foil sensors applied, the app either helps the fitter to calibrate his torque wrench at one or two bolts or it signals that the defined bolt force has been reached for every single bolt.

3 Tests and Results

To verify the quality of the foil sensors we conducted several test series at our laboratories of UAS Muenster. The tests were performed at room temperature and at elevated temperatures.

In the first experiment, the foil sensor was loaded with plane surfaces in a gasket test bench. For this purpose, special cylinders were made that were then clamped between the test plates and were also equipped with their own temperature sensor. The foil sensors were then gradually loaded step by step and the pressure applied was 20 kN, 40 kN, 60 kN, 80 kN, 100 kN respectively, where the surface under load was 638 mm^2. The surface pressure was therefore about 160 MPa. Fig. 5 shows an example of our test setup.

Figure 5: Test setup to validate the foil sensor

As it can be seen in fig. 6, the raw test data shows already promising results. There is almost a linear relationship between the applied bolt force and measured resistance of the foil sensor. Nevertheless, two effects have a negative impact on the measurement results. Firstly, there is a drift at constant force that becomes stronger with increasing force. Secondly, there is a hysteresis that occurs when the load is relieved.

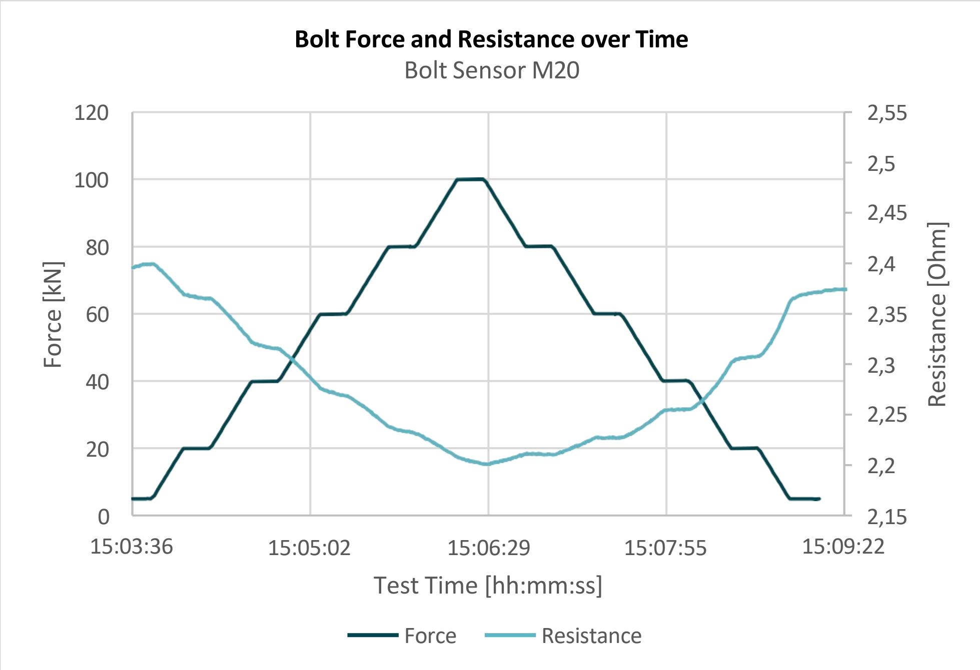

Figure 6: Example of measurement results for an M20 foil sensor

Since we can calculate the occurring drift, this effect might not be a problem during the assembly. The same applies to the hysteresis. If we use our sensor only to calibrate a torque wrench it does not matter whether there is a crosstalk between the bolts with several rounds of loading and unloading. Nevertheless, it is a problem if we want to take advantage of a continuous measurement of all bolts during the assembly. The drift can be eliminated by means of algorithms, but it would be harder to do so for a sensor during operation. At this stage it might be difficult to differ between a drop in the measurement value because of drift and a drop because of the creep-relaxation from the gasket.

Therefore, our project partner is currently developing another version of the sensor and we are confident to be able to eliminate the described effects in the future version.

We took measurements for different positions of the foil sensor under the nut with different alignments. Fig. 7 shows two positions as an example. In the following diagram of fig. 8 the pads are named as follows:

- Pad 1 is the pad on the right lower side

- Pad 2 is the pad on the left lower side
- Pad 3 is the pad on the top

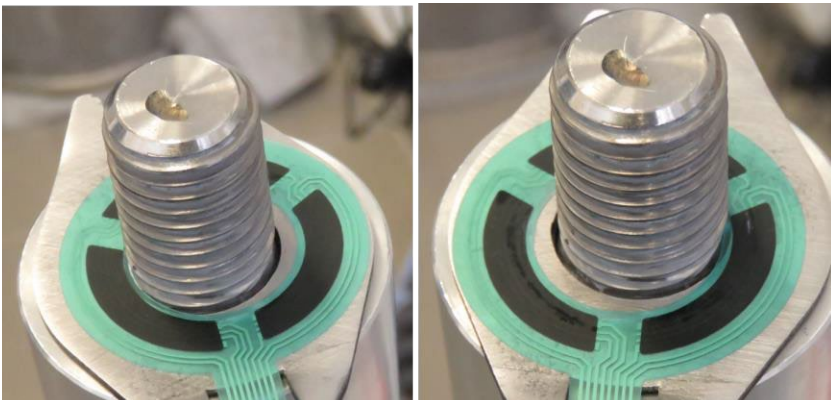

Figure 7: Two different alignments of the foil sensor under the nut

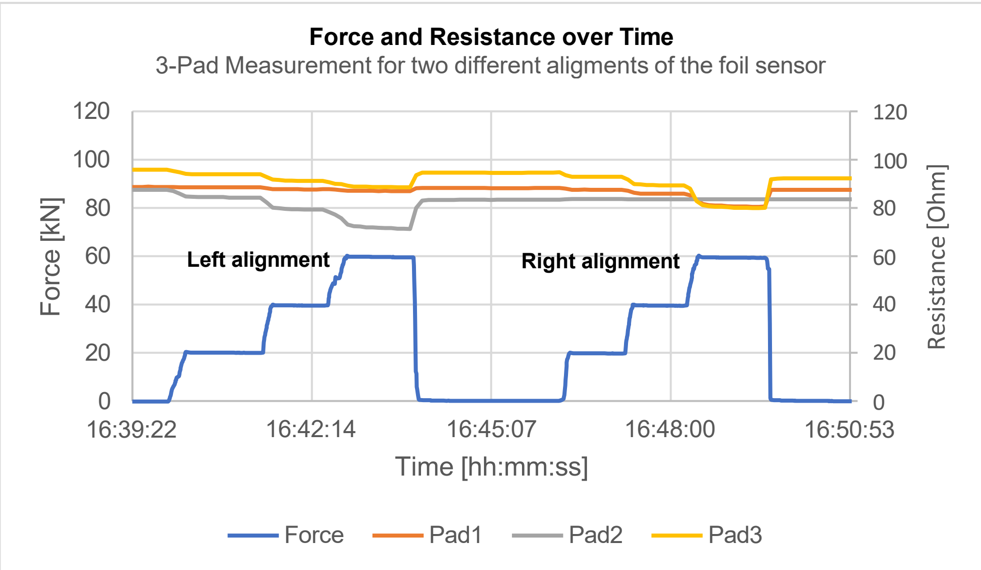

Figure 8: Measurement results for the two alignments from fig. 7.

As we can see, the displacement is immediately visible in the measurement results. In the left alignment in fig. 7 only pad 2 is completely under the nut. This is why we see the major drop in the diagram for the grey curve in fig. 8. After unloading and realigning the sensor as seen on the right side in fig. 7, pads 1 and 3 face the higher load. The same is visible in the diagram with the yellow and orange curve showing the largest deflection.

4 Outlook

Measuring bolt forces at competitive costs and in real-time is only the first step into a smart flange joint. Adding other sensors and meta data like the flange joint location, the operating temperature or a fitter's ID will enable us to offer new insights for the assembly and the life of the entire flange joint.

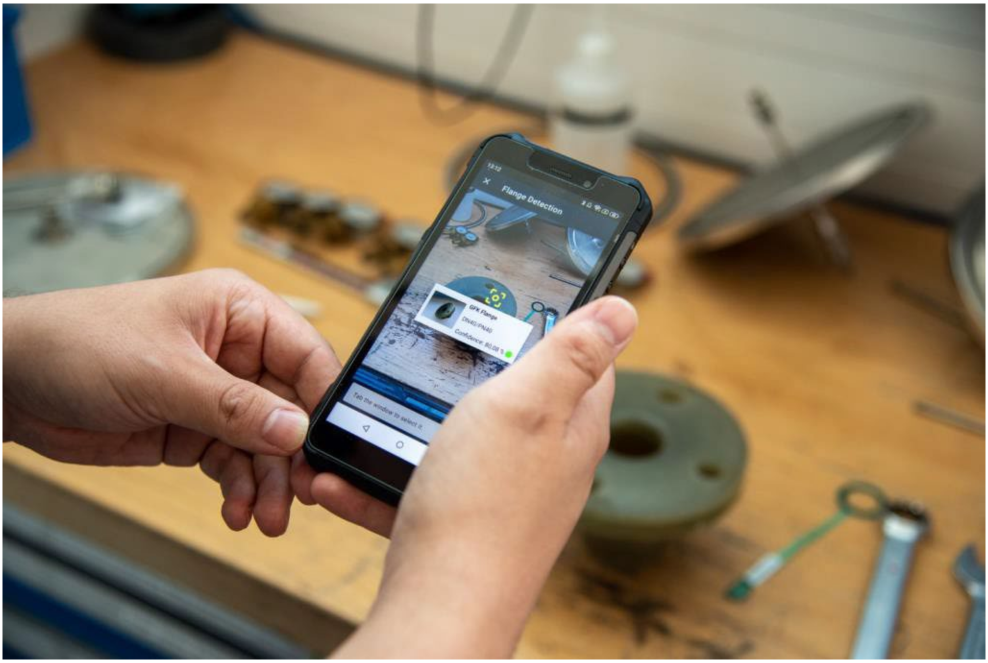

Figure 9: Example of an intelligent flange recognition at UAS Muenster

Whether it is an intelligent flange recognition as shown in fig. 9, help in choosing the right gasket for the considered application or a navigation and routing system to lead the assembly crew through the plant – there are many possible add-ons that can be implemented within our app to make flange joints as safe and easy as never before.

If we manage to further develop the assembly sensor into an operating sensor, we would be able to predict the remaining lifetime of a gasket, warn the operator in case of irregular events and elongate maintenance intervals.

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