Torque Measurement and Statistical Process Control of Bolted Connections

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Abstract- **The precise control of torque is a key to quality assembly and can ensure that products perform as expected. A single fastener, inaccurately or incorrectly tightened, can lead to the failure of a product, which impacts the bottom line. In many cases, companies spend a great deal of time and money for disposal or repair of damaged parts during assembly, the result of improper torqueing. Therefore ensuring that nuts and bolts are sufficiently tight plays a vital role in ensuring the structural integrity of many types of equipment. This paper shows the measurement of residual torque at bolted connections and statistical process control of the same.**

Index Terms- **Torque, Bolted connection, Torqueing, Quality.**

I. INTRODUCTION

In many applications the clamping force provided by tightening bolted connections is of critical importance in determining the success, or otherwise, of the structural integrity of an assembly. A great deal of attention is often placed on ensuring that bolted connections are installed in a controlled manner such that a predictable clamping force is achieved. In the majority of applications the bolts are required to provide a minimum clamping force such that the joint will be capable of resisting the external forces so that joint separation and joint movement are prevented.

The most popular method of tightening a threaded fastener is by applying a specific tightening torque. Below the yield point of the fastener, the relationship between the applied tightening torque and the subsequent clamp force provided by the fastener, is a function of its geometry (thread details and bearing face dimensions) and the coefficient of friction acting between the mating threads and between the bearing face of the fastener and the joint surface. Once tightened, the clamp force provided by a bolted connection can decrease. The decrease can occur without any rotation of the thread, as in the case of stress relaxation, embedding, creep and similar effects, or, the bolt or nut may rotate decreasing the clamp force as in the case of self-loosening. Research has shown that self - loosening of bolts/nuts is normally the result of repeated transverse displacement of the joint. Such loosening can be prevented by ensuring that the bolts provide sufficiently high clamp force to resist the external forces being applied to the joint. Subsequently, concern over the loosening of bolts, in many applications, necessitates the checking of their tightness. Tightness, in this context, is the magnitude of the clamp force being provided by the bolt or a threaded fastener in general.

Currently, the tightness of a bolt/nut assembly is usually assessed by a torque based method; the approach is referred to as torque auditing. Torque auditing is usually completed by one of three torque methods:

1. On-torque method: Measuring the torque needed to rotate the bolt/nut by a small angle (typically 2 to 10 degrees) in the tightening direction.
2. Off-torque method: Measuring the torque needed to rotate the bolt/nut in the untightening direction.
3. Marked fastener method: Marking the position of the bolt/nut relative to the joint, untightening it by an angle of approximately 30 degrees, then measuring the torque needed to tighten the bolt back to the marked position.

The key assumption in each method is that the torque value measured is a true assessment of the tightness of the connection & the coefficient of friction has not changed between the tightening of the bolt/nut and the completion of the checking process.

In this work, On-torque method is used for measurement of torque at bolted connection. Torque is measured with help of Freedom3 tool.

Fig. 1 Freedom3 digital torque wrench

Also to control the quality of the process, Statistical Process Control (SPC) is done with the help of QS-Torque software. The major goals of SPC are;

- Keep under control the quality of a process
- Preventing errors
- Reducing costs for problems occurring on the units coming out from a process (or a production line)

II. TORQUE MEASUREMENT AND SPC

1) Torque measurement

Torque at the bolt is measured with the help of Freedom3 digital torque wrench, by fitting the wrench at bolt head and rotating it in the direction of tightening. Tool is rotated until bolt starts turning (bolt should turn around 2-10 degree).

Fig. 2 Torque measurement

2) Statistical Process Control

Statistical process control consists in a set of statistical tests performed on a process. SPC techniques evaluate the variability of a process, so to identify the probability of non-conformities.

SPC is done with the help of QS-Torque software

SPC involves calculation of following;

I. Standard deviation

$$S = \sqrt{\frac{1}{(N-1)}\sum_{i=1}^{N}(xi - x\ mean)}$$

S = standard deviation
xi = each value of dataset
x mean = the arithmetic mean of the data
N = the total number of data points

II. Machine capability (Cm) & Process capability (Cp)

- Cm is a machine capability index which is kept constant at 1.67. (nutrunner is used for tightening bolted connection)
- Cp is a process capability index. Cp Estimates what the process is capable of producing if the process mean were to be centered between the specification limits.
- Cp & Cm has the same meaning, but Cp is applicable to process and Cm is applicable to machine (tightening tool)

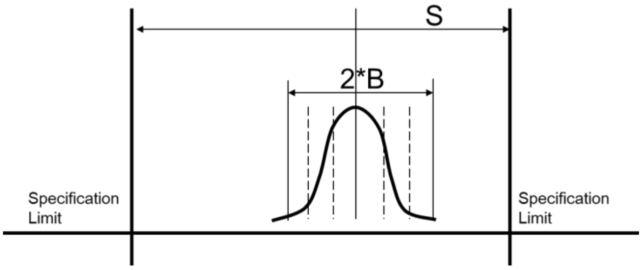

Fig. 3 Bell curve indicating S & B

Cp can be calculated as, $= \frac{S}{2\,B}$,

Where,
S = Distance between lower and upper tolerance
B = 3 Standard Deviations (also called "3 Sigma")

III. PROCESS CAPABILITY INDEX (CPK) AND MACHINE CAPABILITY INDEX (CMK)

- Cmk and Cpk is to study the position of the machine or process capability in relation to the target value, we use the Cmk or Cpk index, which evaluate the capability corrected for position.
- A high Cmk/Cpk index means that the machine or process has small spread in relation to the tolerance width, and it is well centered within that width.

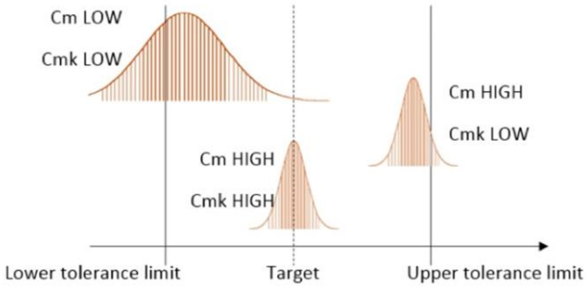

Fig. 4 Bell curve for various values of Cm & Cmk

$$Cpk = \min\{\left(\frac{Upper\ limit - Avg\ value}{3 \times \sigma}\right), \left(\frac{Avg\ value - Lower\ limit}{3 \times \sigma}\right)\}$$

Highher the value of Cp more the process is stable.

If Cp and Cpk are more than or equal to 1.33 tightening process is stable.

III. CALCULATIONS

Explained here below is a bolted connection of a reference car, where 100 samples of same connection have been measured and calculations are performed.

Target value of torque = 36.5 Nm
Upper limit: 41.5 Nm
Lower limit: 25 Nm
Mean of 100 samples = 33.64 Nm

Control charts gives a picture of the machine or process trend. The machine or process can be inspected/adjusted before it goes out of control. In the following example, the process is within the specification and under control.

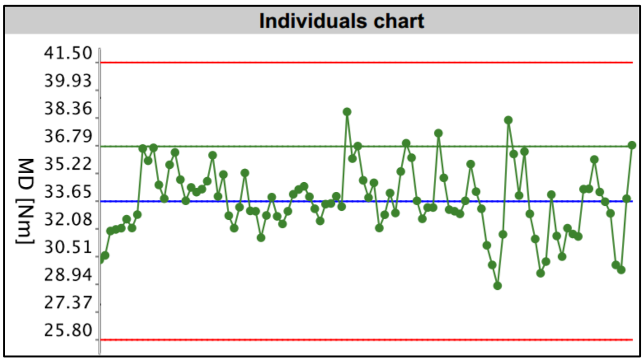

Fig. 5 Individuals chart

Standard deviation of 100 samples = 1.94

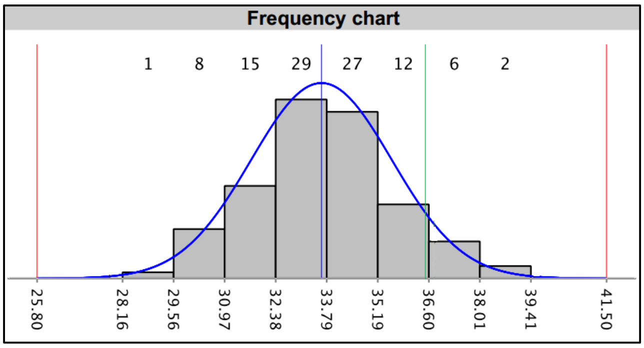

Fig. 6 Normal distribution curve

$$Cp = \frac{S}{2\,B}$$

= (41.5 – 26) / (6 x 1.94)

= 1.34

Cpk = min [(41.5 – 33.64)/ (3 x 1.94), (33.64 – 26)/ (3 x 1.94)]

= 1.35

IV. PRACTICAL IMPLEMENTATION OF SPC

A car manufacturer decides to implement the SPC on its production line.

- Before adding a new tightening tool to the production line, and then once every month, a Cm-Cmk test is run on the tool

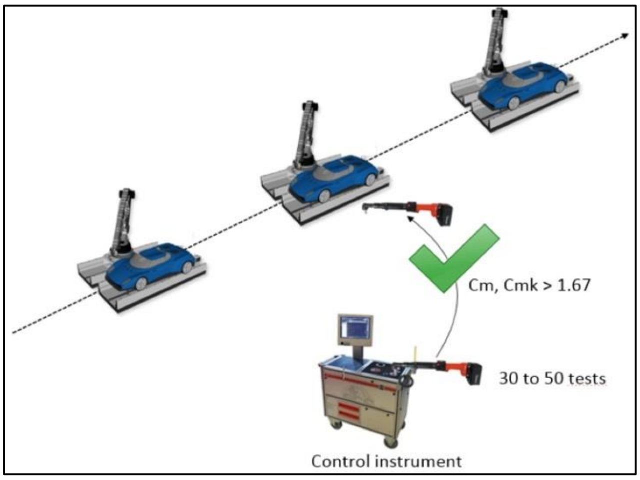

Fig. 7 Cm, Cmk test of tightening tool

- Each day, the tool is removed for few seconds from the line, and it is verified trough a statistical control test, to build X,R charts.

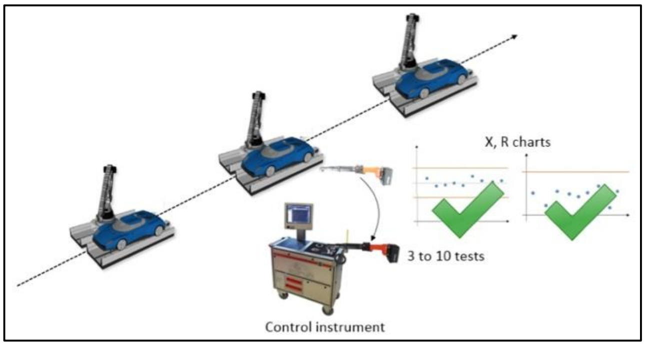

Fig. 8 Statistical control test of tool

- Each day, residual torque tests are executed at the end of the production line, to verify the process (using Cp-Cpk and/or X,R charts)

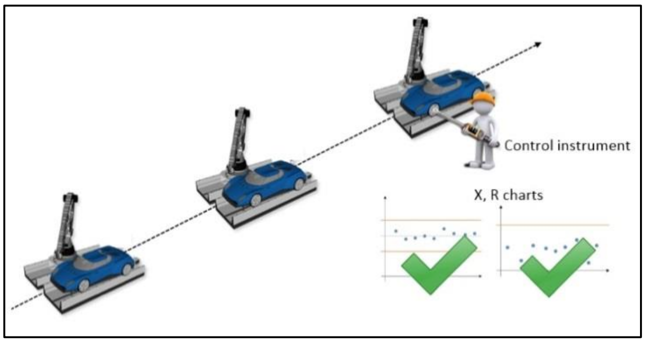

Fig. 9 Residual torque test

- All the results of the Cm-Cmk, Cp-Cpk, X,R charts are stored in a database for analysis, traceability and reporting

Fig. 10 Result output from database

V. CONCLUSION

1. All the samples are within the specified limits.
2. Values of Cp and Cpk more than 1.33 hence process is stable
3. Quality of all bolts is under control.

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