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Maintenance intervals for MP-TP bolted connections – A case study

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ABSTRACT

In offshore windfarms there has recently been an increasing trend in the use of large diameter bolted connections for the connection between the Transition Piece (TP) and the Monopile (MP). The dimensions of such connections cause handling challenges due the size of the bolts, often M72. An cost driver for these connections the need for maintenance: neither the maintenance intervals nor the maintenance scope can be clearly deferred from standards, and industry experience specifically on these large diameter flanges is generally limited. For these offshore installations, maintenance costs and HSE risks can be high due to the difficult accessibility of these bolted connections offshore often in confined spaces. I n addition, maintenance periods should preferably be scheduled in good weather seasons. This paper describes a case study whereby inspection results are used to set the interval to the next inspection with the purpose of minmizing the maintenace costs.

1. Introduction

The windfarm in question has a bolted MP-TP connection consisting of 50 assets 84 bolts M72 class 10.9, all of which are equipped with tension-controlled fasteners (TFC) (4200 bolts in total). The purpose of choosing such tension-controlled fasteners is threefold: firstly, better control over the initial preload ensures the minimum preload is always achieved, and therefore less bolts are expected to relax below the permanent required preload. Secondly, the tension-controlled fasteners allow for preload inspections without significant tools, which is of major importance given the difficult accessibility of these bolted connections and the costs associated to such inspections. Thirdly, when re-tightening is needed, the scope of works can be reduced to only the bolts that require re-tightening, and if needed the adjacent bolts.

Inspection results of all bolts have been captured for a period of over 3 years and based on that an attempt is made to set and update an interval for inspection and potential re-tightening.

2. Background

The tension-control device on the bolts is set so that the minimum permanent preload (70% of f_y according to Ref. [2]) and the upper limit for installation (set to 77% of f_y) are indicated as a fail/pass criterion. During installation, all bolts were torqued to reach a preload of 77% of f_y, irrespective of the torque required to achieve this. During the further installation of the windfarm, several inspections of the bolts were done within a period of up to 230 days. Each bolted connection was inspected 3 to 4 times. After that, the bolts found with preload below 70% were retorqued again to reach the 77%. The following inspection campaign happened 18–24 months later, after which all bolts below 70% preload were retorqued. A third inspection campaign was carried out about 1 year later.

For this whole document, a bolt is considered as loose if its preload is below 70% of f_y.

The purpose of this study is to investigate the evolution of the number of bolts getting loose with time in order to set safe inspection intervals. Upon each inspection, the model parameters can be updated which should hopefully increase the interval to the next inspection.

3. Methodology

The TFC only provides the actual bolt status in a binary way (loose or not), without time history. The bolt could have become loose just after the previous inspection or just before the current one, which correspond to the earliest and latest boundaries on timing. The interval between consecutive inspections is reasonably short during the first campaign (approx 2 months) allowing a model to be built. For the later campaigns, the interval becomes 1–2 years, and only tuning of the model is possible.. In addition, during the inspection campaign following installation, each bolted connection was inspected several times before re-tightening the bolts, while one single inspection was performed for subsequent inspection campaigns. More information is thus available from the 1st

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campaign. The model for bolt loosening will be established based on the first set of data, and further updated to the 2nd and 3rd ones.

For the analysis of the 1st campaign, the evolution of loose bolts is assessed for the earliest and latest possible time of bolt getting loose. An analytical function is then fitted to the data and forced to fit between the boundaries. The function is expressed in Eq. (1), where t denotes the time and A, B, C are parameters to be fitted

$$f(t) = A * \left(1 - \frac{1}{B * t^C + 1}\right) \quad (1)$$

Eq. (1). is based on the following assumptions:

- No bolts are loose just after tightening, i.e. $f(0) = 0$.
- The function is asymptotic for an infinite time, i.e. $f(\infty) = A$. This denotes the assumption that the most bolts get loose at the early stages and the phenomenon of loosening tends to stop after a given time. This is based on industry experience.
- The loosening process over the entire population of bolts is assumed to be smooth over time
- The bolts over various foundations represent a homogenous population
- B and C are constants

For the subsequent campaigns, the number of loose bolts is listed and related to the number of days between the current and previous inspections. This number of days corresponds to the upper boundary of time for the bolt getting loose, the lower one being 0 day. For each turbine, this duration is different, depending on the inspection dates. It is assumed however that the evolution of loose bolts follows the trend depicted by Eq. (1). It is further assumed that the time parameters (B and C) remain unchanged; these parameters are considered to cover system properties related to non-rotational bolt relaxation such as geometric tolerances, surface roughness, surface protection, Parameter A is the tuning parameter. Thus, the value of A is fitted in order to get $f(t^*) = P$ where t^* corresponds to the P5 of time intervals between inspections for all turbines and P is the number of loose bolts noticed during the inspection.

4. Results

Results of the first inspection campaign after installation, during which each bolt was inspected 3 to 4 times before being re-tightened, are presented in Fig. 1. The dots in orange and blue correspond to the earliest and latest boundaries respectively, i.e. the bolt became loose just after the previous inspection or just before the current one respectively, and the grey dots are the mean values between the boundaries. The horizontal axis corresponds to the number of days between installation and inspection for each individual connection. For a complete representativity of the farm, results are displayed once each bolted connection was inspected at least once. Eq. (1). is fitted[1] providing the following parameters: $A = 0.0560$, $B = 0.0022$, $C = 1.3491$.

Data and fitted functions for the following campaigns are provided in Fig. 2. The number of days corresponds to the period between the previous re-tightening and the inspection and is different for each foundation. The temporal of the observed data extends between P5 and P95 of all periods (all inspections intervals below 5th percentile and above 95th percentile were considered outliers). The parameter A of Eq. (1). is adjusted to fit the data at P5 of time, parameters B and C remaining unchanged. For the 2nd and 3rd campaigns, we obtain $A = 0.0344$ and $A = 0.0102$ respectively.

[1] Using the *nonlin_curvefit* function of GNU Octave.

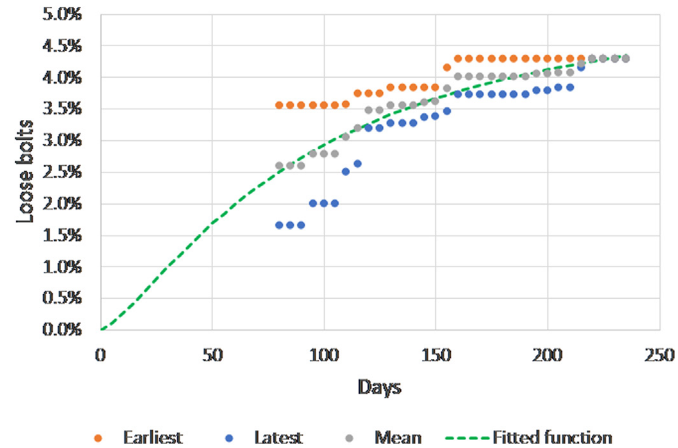

Fig. 1. Evolution of bolt loosening during the 1st campaign.

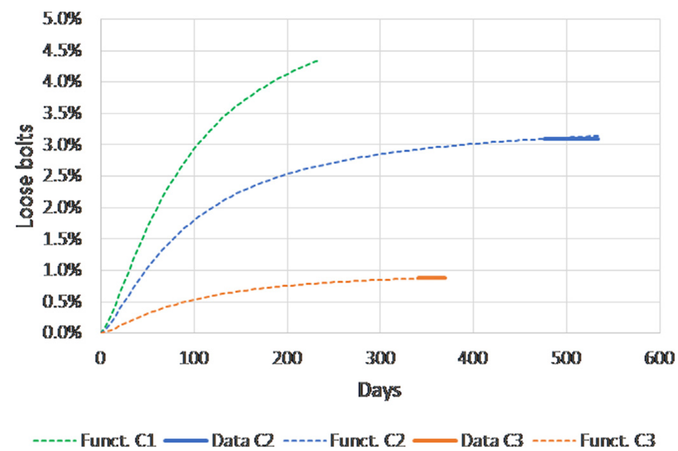

Fig. 2. Evolution of bolt loosening during the 3 campaigns.

5. Inspection interval

Based on these findings an inspection interval can be established. The target inspection interval should be linked to the risk of having too many loose bolts. In this case, the target is set to 3% of all bolts, corresponding to 2 to 3 loose bolts per foundation. This value can be set based on the utilization ratios for the various limit states from the design of this particular windfarm.

Using the 3% criterion in this case leads to a proposed inspection interval of approximately 500 days based on the second period. After that, the inspection results can be used to tune the model again, as required.

After updating the model for the 3rd campaign, it is found that the number of loose bolts after infinite time is just over 1%; corresponding to approximately 1 loose bolt per foundation. Therefore the Operator can now base the next inspection interval on the acceptable number of loose bolts for either a temporary condition (up to the next inspection), or even for the permanent condition, in which case the inspection sample size (and therefore cost) can be reduced.

6. Statistical assessment

The influence of sample size was assessed to see if an inspection of fewer turbines (smaller sample size) would give similar results, and it was found that there is a large difference between the number of loose bolts found in the different foundations, which cannot be explained at this point. This implies that rather large sample sizes are required, and therefore it is recommended to inspect a rather large number of turbines, at least 30–50%.

Bolts were found loose at all locations along the flanged connection and no link with metocean conditions, such as wind or wave main direction can be established, nor with fabrication tolerances.

7. Conclusion and further work

It is found that the use of tension-controlled fasteners results in relatively low amounts of bolts losing preload below target, and significantly reduced the maintenance efforts (with only 5% and 3% of bolts needing retorque). Further, it is found that the amount of bolt loosening decreases after retorqueing. Finally a method is proposed for setting inspection intervals. The combination of the above shows good potential for achieving low maintenance bolted connections by using tension-controlled fasteners.

For this particular case, a permanently acceptable state has been reached after approx 4 years, hence it is suggested to reduce the inspection sample size.

Future inspection results should be used to validate the work in this paper. If improvements in data quality can be achieved (actual preload values in stead of fail/pass criteria) then the model can also be significantly improved in terms of robustness.

Future work could involve the validation of this work on other similar structures, further research into the proposed parameters A, B and C and their dependence on the various parameters of these bolted connections, such as tolerances.

Declaration of competing interest

The author declares that no conflicts of interest are identified related to this publication.

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