Condition Health Monitoring of Monopile and Transition Piece Using Guided Wave Testing

Kena Rachel Makaya
Plant Integrity Limited
Great Abington, Cambridge, United-Kingdom

George Emmanuel Varelis, Alex George Roff
PDL Solutions (Europe) Limited
Hexham, Northumberland, United-Kingdom

ABSTRACT

Wind turbine supporting monopiles may contain over 1km of weld and potential sites of cracking may not be easily predicted. While the design of turbine structures aims to minimise the risk of fatigue cracks occurring, small imperfections may initiate cracks and, while welds are more likely to suffer in this way, cracks may occur almost anywhere on the structure. This paper presents the capabilities of the Guided Wave Ultrasonic Testing method to detect simulated cracks across a large volume of material, in combination with a fatigue assessment methodology that will be able to provide remaining fatigue life estimations of the monopile.

KEY WORDS: Offshore Wind Turbines, Monopile, Fatigue cracking, Guided Wave Ultrasonic Testing.

INTRODUCTION

In the early 1970s, when the first deep water northern North Sea installations were being developed and installed, the ability of the ‘jacket’ structures to withstand the service conditions offshore for their whole design life was very uncertain. There was considerable uncertainty about the accuracy of predictions of both magnitude and frequency of cyclic loading from wave action and about the endurance of the complex tubular structural details in the ‘jacket’ structures under such fatigue loading. In consequence there was a rapid development of techniques and deployment methods for underwater non-destructive testing (NDT) in order to provide assurance that structural integrity was not being affected by fatigue cracking and other degradation. In parallel much work was done to establish the fatigue endurance of the various tubular-to-tubular joints and the means of improving it. From the mid-1970s to the mid-1980s a large amount of coordinated research was carried out mostly under the auspices of the Department of Energy, under the UK offshore steels research project (UKOSRP) and others, into loading conditions, steel properties and suitable inspection methods (Department of Energy 1979 & 1984). This considerable research effort improved the fracture and fatigue properties of steels, particularly for BS4360 Grade 50D – widely used for offshore construction, the knowledge of fatigue endurance of large-scale welded tubular joints in jacket structures and of the influence of both seawater and loading from wave action on fatigue life (Booth 1981).

Initial conservative assumptions and design improvements arising from the findings of these programmes have enabled safe and reliable operation of most installations in the North Sea and most are still in operation. However, much of this accumulated experience cannot be directly applied to the structures supporting wind power generators offshore. The loadings are quite different, with large turning moments on the foundations arising from the tall towers and forces arising from both the weight of the generator itself and the drag from the interaction of the blades with the wind, so that service data from oil and gas production platforms cannot easily be translated to wind power structures. Further, designs such as monopiles lack the structural redundancy of lattice jackets, so that there are no alternative load paths if cracking occurs. Continuing trends to install larger capacity turbines, of the order of 5MW, up from around 3MW previously, and for installations in deeper water further from the shore tend to exacerbate the level of uncertainty in life prediction owing to lack of concrete information about input values for life calculations.

Prediction of fatigue crack initiation and growth is highly dependent on the loads applied. Crack growth proceeds in an exponential manner according to the Paris-Erdogan equation (Paris & Erdogan (1963)): 

\[
\frac{da}{dN} = C(\Delta K)^m
\]

Where \(a\) is crack depth, \(N\) is the number of load cycles, \(\Delta K\) is the stress intensity factor range – which is proportional to the load, amplified by the stress concentration at the crack tip. The parameters \(C, m\) are dependent on the material and the environment of operation. Reference values are given in international standards, e.g. BS 7910 (2005) and API 579-1/ASME FFS-1 (2007).

It can be seen that the crack growth rate, \(da/dN\), is therefore heavily dependent on the stress intensity factor at the crack (which itself increases as the crack grows), so that any uncertainties in prediction of the loads on the structure (and therefore on the stress intensity factor)