A Comparative Assessment of Cutting Techniques for Offshore Energy Structures

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Abstract* – *This study presents an overall assessment of the current five most conventional cutting technologies in the offshore industry from the economic, production, safety, and environmental impact viewpoints. The applicability, advantages, and disadvantages of each cutting technique for cutting operations of jacket structures are summarised. The cutting times required by different techniques are investigated for decommissioning of jacket structures with different diameters and wall thicknesses. The study provides overall suggestions on the suitability of techniques for cutting offshore foundation structures.

Keywords- Assessment, Offshore, Cutting, Jacket, Structures, Decommissioning, Energy.

I. INTRODUCTION

The decommissioning of numerous offshore installations is expected to take place in the coming years. The Oil and Gas (O&G) and offshore wind installations in the North Sea Region (NSR) are reaching their end of lifetimes. There are plenty of monopile and jacket foundations that need to be dismantled from the seabed. The biggest challenge in foundation removal activities is the time required for cutting the foundations. The offshore decommissioning operations are usually performed by expensive vessels/equipment that can significantly affect the overall project budget. The current foundation cutting techniques are time-consuming. This highlights the fact that the new technological innovations are essential for reducing the rental duration of vessels/equipment and the overall project duration.

There are different techniques currently employed for offshore cutting operations, including Diamond Wire (DW), Abrasive Water Jet (AWJ), Oxy Arc (OA), Laser Beam (LB), and Plasma Arc (PA). These cutting techniques can be categorised in several ways. They may show different performances under different circumstances. Hence, the suitability and applicability of the cutting techniques for different purposes need to be investigated.

The main aim of this study is to provide an overall assessment of the conventional cutting techniques in the offshore industry from economic, production, safety, environmental impact, and applicability viewpoints. The performances of the different cutting techniques are evaluated on the jacket structures with different diameters and wall thicknesses. The study investigates the applicability of each technique for internal or external cutting operations and summarises their advantages and disadvantages. The study also compares the cutting times required by the different techniques for the pipe sections with different dimensions.

The rest of the paper is organised as follows. Section II provides an overview of the conventional cutting techniques widely applied in the offshore wind industry. Section III presents the numerical results and comparisons between the different techniques. Finally, Section IV presents the concluding remarks yielded from this study.

II. OVERVIEW OF CURRENT CUTTING TECHNIQUES

As was mentioned earlier, the commonly used conventional cutting techniques for tubular foundations are DW, AWJ, OA, LB and PA. as illustrated in Figure 1. all of these techniques can be employed for external cutting, whereas the DW is only developed for external cutting. AWJ is the most commonly applied cutting technique for the internal cutting operation of tubular foundations. The mentioned cutting techniques can be evaluated by considering different performance criteria, including: cost, cutting speed, energy consumption, safety and applicability, as well as the material they can cut. In the following subsections, the mentioned cutting techniques are explained in detail.

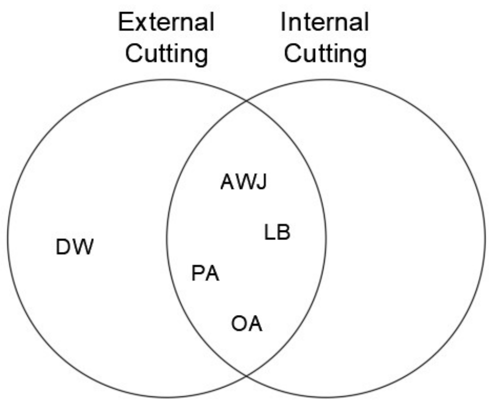

Fig. 1. Venn diagram illustrating the applicability of different techniques for internal and external offshore cutting operations

A. DW Cutting

DW is a technique widely used for cutting the jacket and tubular foundations in open spaces [1]. Due to its limited versatility, the DW technique can only be applied for external cutting, as the running loop of the wire bow needs access to both sides of the cutting material. The efficiency of the DW is directly related to the amount of pressure applied to the wire bow. The cutting depth of the DW into steel is proportional to the wire string's speed and plating thickness [2]. Therefore, it is expected that the higher wire speeds or regular changes of wire can enhance the efficiency of the DW technique. The wire used in the DW technique can be a subject to the fatigue phenomenon; something which can lead to limited tool life and fast deterioration of the wire. Hence, the fatigue phenomenon can potentially reduce the productivity of cutting operations in the DW technique [3].

The DW cutting technique is a safe way to remove or replace part of a steel structure. This is an eco-friendly cutting

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technique that does not harm the marine life [4]. The quality and precision of the cutting process carried out by the DW are highly dependent on the wire bow's stiffness which can significantly impact the cut's quality and surface texture [5]. Regarding to the energy consumption, the DW needs low energy input for its operation [6]. It also has low noise levels and produces almost no dust or vibration during its cutting operations [7]. From the work safety and environmental point of view, the DW is a good option for the decommissioning of jacket foundations [8].

B. AWJ cutting

AWJs are widely used to cut steel structures in the offshore industry, both at topside and subsea levels. Due to the high cutting precision of the AWJ and its low impact on the environment, this technique is the preferred choice for the internal cutting of offshore monopile foundations with large wall thicknesses. The AWJ is applicable to cut a range of materials with thick surfaces [9], [10], for which other cutting technologies have some limitations. In terms of cost, the AWJ is an expensive option compared to other cutting techniques applied in the offshore industry. However, its high versatility and relatively low environmental impact make it an attractive cutting tool under given conditions [11]. The cutting speed of the AWJ is lower than other methods [11], which highly depends on the surface thickness and the quality of the kerf surface area [12]. The cutting depth of the AWJ depends on the water pressure [13].

The AWJ is an energy-intensive cutting tool, as its pump and compressor unit need to create a high pressured and steady water stream to provide an efficient cutting capacity [14]. Abrasive particles are often added and mixed into the water supply of the AWJ cutting machine [15]. Due to the high cost of the abrasives, the AWJ cutting tool has a high operation cost [9]. The AWJ is a safe and environmentally friendly cutting approach as it includes only highly pressurised water with no hazardous chemicals or vapour. Nevertheless, the material debris propagated around the cutting area due to the high pressure of the AWJ cutting tool can pollute the environment [1]. Moreover, since the cutting force only contains water and abrasives, the AWJ cutting tool is an ideal choice for cutting operations in flammable or explosive environments [16].

C. LB cutting

Laser cutting is used at both topside and subsea levels in the offshore industry. This technique is applicable for cutting both carbon and stainless steel, as long as they do not have a reflective surface. One significant advantage of laser cutting over other techniques is its ease of use, as it can be remotely operated during the cutting process [17]. Although the LB tool can handle up to 60 mm thick steel plates, its cutting speed can be significantly reduced for the thicker steel plates [18], [19]. The LB can be viewed as one of the more precise cutting tools in the market with a narrow cutting kerf [17]. The left width in the LB tool is dependent on the power and focus of the laser beam, the inlet gas pressure, and the cutting speed [20]. Therefore, the performance of LB cutting can be further optimised by manipulating these parameters.

Although the LB provides a good quality cutting performance [21], its kerf surface smoothness is a bit lower than those yielded by other techniques. However, the quality of the kerf surface yielded by the LB can be improved by adding a noble gas, such as nitrogen, as the inlet gas of the laser [17]. Another drawback of the LB approach is its heat emission resulting from the intense laser beam during the cutting process of a steel material; something which can cause thermal defamation [11]. Lower cutting speeds of the laser will intensify the size and temperature of the heat-affected zone on the material surface and increase the risk of thermal defamation [22]. It should be noted that the LB is one of the fastest cutting technologies in the market for the steel material [23].

Laser cutting has the advantage of producing a lower amount of waste material from cutting operations, as all excess material resulted from the cutting process are burned away by the laser beam's energy [17]. This shows that the LB can be considered as an environmentally friendly technology. From an economic point of view, the LB can be categorised as a moderate cost-cutting technology in the market with high equipment costs and lower operational costs [24]. In terms of energy efficiency, the LB requires significantly lower energy than other techniques in the offshore industry [18]. From a safety point of view, the LB is dangerous to human life. This means that the LB must be operated by professionally trained and skilled labour, or preferably, at a remote distance [25]. Regarding the environmental impact of a laser cutter, it emits hazardous vapours from the laser beams burning under its operation. However, laser cutting poses no further impact on marine life or the environment [11].

D. PA cutting

The PA is a cutting technology invented in the 1950s [26]. It is a popular cutting approach, as it can be employed to cut a range of materials, including carbon steel, stainless steel, alloy steel, aluminium and other conductive materials [27]. The PA is flexible enough to perform the cutting process of both topside and foundation structures in the offshore industry [28]. The technique uses gas, such as a mixture of argon and hydrogen, which travels through a nozzle at high speed [29]. The PA is capable of cutting most steel types with the corroded surface. However, the PA tool is not a suitable option for composite and multiple layered materials.

The PA is one of the fastest cutting technologies in the market. It is four to five times faster than the OA cutting tool and can be over twice as fast as LB cutting for thin steel plates. The tool has been reported as being an overall faster cutting technology for thick steel plates [30]. Regarding the operation cost, using a PA cutter is among the cheapest single-operation cutting technologies in the market; slightly lower than that of a LB cutter [11]. One of the disadvantages of the PA cutting method is that it causes dross formation on the steel material due to the extremely high temperature of the cutting process. The dross formation and the extra heat reduce the accuracy of the cutting process, according to [31].

The PA provides a good quality and narrow cutting kerf surface [32]. The roughness of kerf surface of the steel objects is slightly higher compared with the other cutting technologies and it is less precise in its cut and quality smoothness of the surface kerf than that of a LB cutting [21]. The roughness of the kerf surface of the steel objects is slightly higher compared to the other cutting technologies, and less precise in its cut and quality smoothness of the kerf surface than that of a LBcutting [21]. Nevertheless, the high heat output of the PA cutting creates a significant area of thermal deformation in the cutting zone [11]. Regarding the safety and environmental impact, the PA cutting emits hazardous vapours during the cutting process of steel materials. The PA cutting process also has the risk of dripping liquid steel from the cutting area due to dross formation created by the high temperatures [33].

E. OA cutting

The OA is one of the market's most widely used technologies for cutting different materials, especially for steel. The OA can be categorised as an underwater thermal cutting technique [34]. Due to its capability in cutting the steel objects with larger thicknesses, the OA has been employed in the offshore industry for cutting carbon steel objects such as monopile structures [35]. However, the technique might not be an ideal choice for cutting thin steel objects. The OA is particularly suitable for the cutting the steel objects, as the ignition temperature of the cutting material must be lower than its melting point, otherwise, the material would start to melt instead of being cut [36].

From a cost viewpoint, the OA technique is typically cheaper than the PA method. The OA offers the cheapest cutting tool for the cutting of the carbon steel object. However, the costs can be affected by variations in gas prices. The cutting speed of OA is slow, and it needs to be operated by highly skilled labour [34]. The cutting speed of the OA tool is approximately the same as for the AWJ technique. As the OA mainly operates using the gas, it requires less electrical energy comparing to other techniques [35]. Due to the liquefaction of the steel during the cutting process, the technique provides lower cutting quality and precision. Therefore, it is usually replaced with either LB or PA cutting techniques [30], depending on each case. The OA creates lots of dross at the bottom of the surface kerf; something which leads to a more rough kerf surface compared to the other thermal cutting techniques [37].

Regarding the environmental impact, there is a slight chance of gas leakages from the gas tanks used for the OA cutting process and these pose the highest risk to the environment. There is also a risk of a gas explosion that can potentially put the marine life around the cutting area at risk. In terms of the safety of the cutting process, the usage of OA is not recommended in flammable areas due to the high operating temperatures and ignited gasses which can cause the risk of explosion to the operators. There is a risk of ignition of the steel dust particles in the air resulted from the OA cutting, which can potentially cause an explosion in the working zone [38]. There is also a slight chance of dripping hot liquid steel from the dross of the cutting process. Hence, it is essential for the operators of the OA tool to wear appropriate safety glasses and clothes as well as being fully trained against the possible safety risks [34].

III. COMPARISONS OF THE CURRENT CUTTING TECHNIQUES

This section provides an overall assessment of the cutting techniques explained in the previous section. The assessment and comparisons are performed based on different performance measures, including: economic, production, safety, environmental impact and applicability. This study assumes that the cutting techniques can be employed for cutting the jacket structure with the carbon steel type of A333 Gr. 6 (ISO EN 1.0456), as defined in [39]. Table I lists the dimensions of the most commonly used jacket structures in the offshore industry, in which the sections are categorised into two groups, XS and XXS with wall thicknesses of 12.7 mm and 25.4 mm, respectively [40]. Table II presents the overall performance comparison of the five cutting techniques. It should be noted that the cutting speeds (C_s) data of the XS identification type is based on carbon steel material, with a w_t between 10-15 mm.

The cutting time required by each technique can be calculated based on the cutting speeds as follows:

$$t_c = \frac{\pi D_o}{S_c} \qquad (1)$$

where D_o represents the diameter of the pipe section and S_c is the cutting speed. Using Eq. (1), Figures 2 and 3 compare the cutting times yielded by different techniques for the XS and XXS pipes respectively. The cutting times are calculated for the pipe sections DN250 to DN1000 with diameters between 250 mm up to 1000 mm.

From the comparisons made in Table II and Figures 2 and 3, it can be seen that the PA is the fastest cutting technique. It can also be seen that the thermal cutting methods are generally superior than the non-thermal cutting techniques in terms of the cutting times. However, they provide lower cutting quality, thereby resulting in rougher edges. The thermal cutting methods also often exhibit lower precision than the non-thermal cutting techniques. Due to the fact that the DW and PA techniques cannot handle wall thicknesses over 100 mm, then these may not be employed for the monopile foundations in offshore industry. The DW technique can only be applied as an external technique, which can then lead to further seabed disruptions compared to the other techniques.

IV. CONCLUSION AND FUTURE WORK

This paper has presented an overall assessment of the conventional DW, AWJ, OA, LB, and PA cutting techniques for the foundation cutting in the offshore industry from the economic, production, safety, environmental impact, and applicability viewpoints. The cutting times required by each technique were compared for the XS and XXS pipe sections with carbon steel material and different dimensions. The comparison results showed that the PA is the fastest cutting technique. It also revealed that the thermal cutting methods are generally superior compared to the non-thermal cutting techniques regarding the required cutting times and operational costs. However, they provide the lower quality cut surfaces and they are less precise in comparison to the non-thermal techniques. All the above techniques can be employed for cutting the jacket and monopile structure with carbon steel material. However, the applicability of the DW and PA techniques for cutting the monopile foundations might be limited due to their thickness cutting limitations. The assessment provided in this study was primarily focused on the cutting of offshore jacket structures. Therefore, it is suggested to conduct a deeper assessment of the cutting techniques in future studies.

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TABLE I. CARBON STEEL PIPE OUTER DIAMETER (D_O) AND WALL THICKNESS (w_t) FOR THE OFFSHORE JACKET STRUCTURES [40]

DN	250	300	350	400	450	500	550	600	650	700	750	800
D_o (Inches)	10"	12"	14"	16"	18"	20"	22"	24"	26"	28"	30"	32"
D_o (mm)	273	324	356	406	457	508	559	610	660	711	762	813
XS w_t (mm)	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7
XXS w_t (mm)	25.4	25.4	25.4	25.4	25.4	25.4	25.4	25.4	25.4	25.4	25.4	25.4

TABLE II. COMPARISON OF THE DIFFERENT CONVENTIONAL CUTTING TECHNIQUES EMPLOYED IN THE INDUSTRY BASED ON DIFFERENT PERFORMANCE MEASURES [13], [41], [42]

Cutting Technique	DW	AWJ	OA	LB	PA
Type	*External*	*External/Internal*	*External/Internal*	*External/Internal*	*External/Internal*
Cost	*High*	*Highest*	*Lowest*	*Medium*	*Low*
Cutting Speed (S_c)	*Low*	*Low*	*Medium*	*High*	*Highest*
w_t *12.7 mm (XS)*	[a]*50 mm/min*	*950 mm/min*	*500 mm/min*	*1000 mm/ min*	*2200 mm/min*
w_t *25.4 mm (XXS)*	[a]*50 mm/min*	*365 mm/min*	*400 mm/min*	*900 mm/ min*	*1100 mm/min*
Productivity	*Medium/low*	*Medium/ low*	*Low*	*Highest*	*High*
Precision	*High*	*Highest*	*Low*	*Medium*	*High*
Quality	*High*	*Highest*	*Low*	*Medium*	*low*
Energy Consumption	*Medium*	*High*	*Medium*	*High*	*Highest*
Safety Risks	*Small fragments and cuts*	*Small fragments, abrasive mud and cuts*	*Hazardous vapours, burns and gas explosions*	*Hazardous vapours, aerosol and burns*	*Hazardous vapours, dross and burns*
Environmental Impact	*Medium*	*Medium*	*Medium*	*Low*	*Low*
Ambient Applicability	*All*	*All*	*Non-Explosive*	*Non-Explosive*	*Non-Explosive*
Material Applicability	*All Steels*	*All Steels and Composites*	*All Steels, but mostly Carbon Steel*	*Non Reflective Steels*	*All Steels*
Maximum w_t	*+300 mm*	*+300 mm*	*+300 mm*	*60 mm*	*50 mm*

[a.] The DW cutting applies directional diameter cutting and not circumference cutting in other cutting techniques.

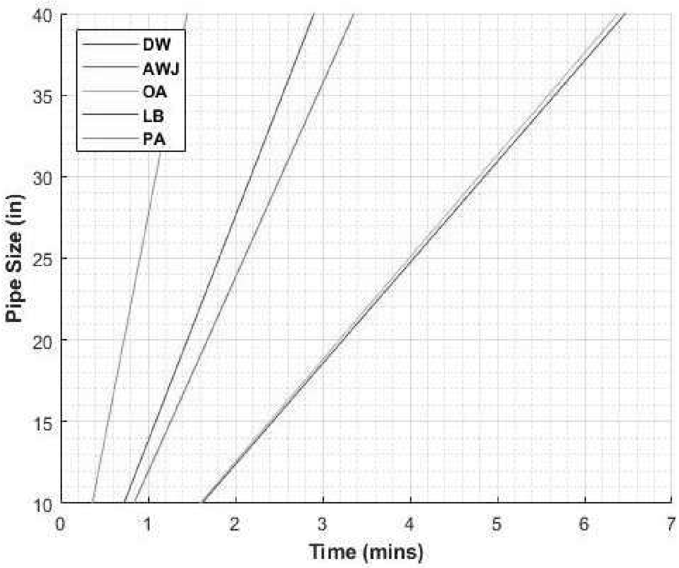

Fig. 2. Comparison of the cutting times (t_c) yielded by the different techniques for different diameters of XS pipe section

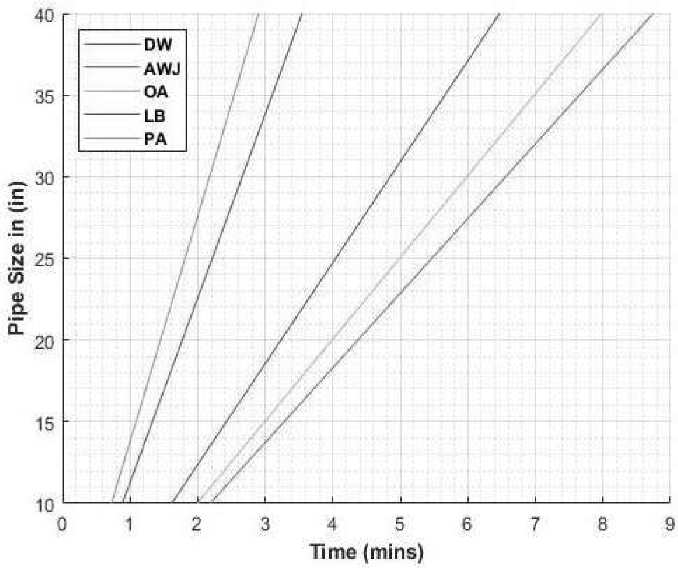

Fig. 3. Comparison of the cutting times (t_c) yielded by the different techniques for different daiameters of XXS pipe section

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