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ScienceDirect

Natural Gas Industry B 3 (2016) 82−89

www.elsevier.com/locate/ngib

Research article

Research and development of a self-centering clamping device for deep-water multifunctional pipeline repair machinery

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Received 8 September 2015; accepted 29 December 2015

Available online 1 July 2016

Abstract

When multifunctional pipeline repair machinery (MPRM) is used in the deep sea area, it is difficult to grip the pipeline and ensure concentricity between the cutter heads and the pipeline during its operation. In view of this, a new system of two-arm holding self-centering pipeline clamping device was proposed. The system is composed of two groups of parallelogram double-rocker mechanism and cranking block mechanism which are symmetrically distributed on the frame. The geometric parameter solutions of the clamping device were analyzed with motion and transmission as the constraints. A mechanical model was established to associate the friction torque of clamping points with the driving force. Clamping device and machinery were designed and manufactured for the Ø304.8−457.2 mm pipelines used in this test. ADAMS simulation experiments were conducted underwater, and the cutting and beveling tests were carried out onshore. The following results are achieved. First, the smaller the pipe diameter, the smaller the transmission angle of the oscillating slider mechanism; the longer the hydraulic cylinder stroke, the greater the transmission angle of the double rocker mechanism. Second, the driving force of the clamping device increases with the increase of the pipe diameter. When the diameter reaches 457.2 mm, the hydraulic cylinder driving force of the clamping device should be greater than 10219 N. Third, the feed rate of the cutters increases suddenly due to the slight shaking of the machinery which occurs at the beginning of the pipe cutting, so it is necessary to adopt a small feed rate. And fourth, onshore experiment results agree well with the theoretical design and simulation results, proving the rationality of the system. The research results in this paper provide technical basis for the research and development of similar engineering prototypes.

Keywords: Deepwater; Submarine pipeline; Multifunctional pipeline repair machinery; Self-centering; Two-arm holding; Clamping device; ADAMS simulation; Experimental study; Bevel

Single-layer welding steel pipelines with minor diameters, large wall thickness and high strengths are extensively used for oil/gas transmission in offshore areas with water depths over 1000 m [1]. Any leakage in such pipelines must be repaired as soon as possible to minimize economic losses and environmental pollution. To repair severely damaged deep-water pipelines, diverless mechanical connection technologies are extensively deployed outside China [2]. These technologies require special equipment and maintenance operations. During the implementation of such operations, operators on the attendant vessel remotely manipulate Remotely Operated Vehicles (ROVs) and underwater facilities. Currently, these technologies are predominantly owned by Statoil, DW RUPE, Subsea 7, BP and ENI/Saipem [3−10]. Prior to pipeline connection, mechanical connectors are required to lower the lifting pipe rack and the supporting pipe rack to lift the pipeline suspended at a predetermined height over the seabed.

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Peer review under responsibility of Sichuan Petroleum Administration.

http://dx.doi.org/10.1016/j.ngib.2015.12.012

In the course, it is necessary to maintain the pipeline in a horizontal position. Then, it is necessary to lower pipeline maintenance tools to perform pre-processing of concerned pipelines, namely, to cut off and remove the damaged pipeline, remove corrosion-resistant coating (Fusion Bond Epoxy, FBE) and weld seams before the fabrication of bevels on both ends of the pipeline. To perform such operations, close coordination of these three tools for pipeline cutting, fabrication of bevels and removal of corrosion-resistant coating (weld seam) is required. Implementation of such operations may involve multiple lifting operations for relevant tools. Moreover, manipulation of such tools by using ROVs in deep water environments may face difficulties in secondary positioning. These difficulties may eventually reduce operation efficiency and increase maintenance costs [11]. Currently, China has facilities and technologies available to repair failed pipelines in shallow waters only. Harbin Engineering University has conducted relevant researches for tools and technologies related to the maintenance of deep water pipelines. With the deep-sea Liwan-3-1 Gasfield in the South China Sea put into production, development of deep water multifunctional pipeline repair machinery became more important.

This paper reviewed technologies related to clamping devices in tools for deep-water pipeline operations. With consideration to the specific features of deep-water multifunctional pipeline repair machinery, structural design of clamping devices has been accomplished. ADAMS simulation experiments were conducted to determine the reliability of such clamping devices. In addition, cutting and beveling tests were carried out by using the prototype.

1. Technologies related to the clamping devices for deep water pipelines

Due to the stationary submarine pipelines and the specific features in deep-water environment, it is impossible to secure pipeline operation tools on the seabed. Internationally, all deep-water pipeline operation tools deploy “two-arm holding” or “one-arm holding” clamping devices to secure relevant devices on the pipeline prior to relevant operations [12,13].

Fig. 1 shows a typical structure of a pipeline clamping device with “two-arm holding”. With symmetric structure, the device is composed of supporting rack, hydraulic cylinder and clamping claw. The supporting rack may have “V” or quarter-circular configurations. By using the device, it is possible to clamp the pipeline from the top. In addition, the device may provide relatively high clamping forces to secure pipelines with certain diameters. However, the device may not be used to rotate the operation tools to align these tools with the pipeline as required for circumferential operations on pipelines with different diameters. Consequently, the pipeline clamping device with “two-arm holding” can be used predominantly for operations without requirements for alignment, such as cutting operations involving diamond wire saw [14] or guillotine pipe saw [15].

Fig. 2 shows a typical structure of a pipeline clamping device with “one-arm holding”. Composed of rack, hydraulic cylinder, guide rail and clamping claw, the device has compact structure with rack and clamping claw in arc configuration. The device can be used to secure the pipelines with certain diameters sideway. When tightened, the rack may in contact with the pipeline in oval arc to facilitate alignment operations. With only one driving cylinder, loads of deep-water hydraulic system can be reduced effectively. Moreover, resulting clamping forces are also relatively small. These devices are predominantly deployed on tools to remove the corrosion-resistant coating of pipelines through milling or abrasion.

2. Working principles and prototype of deep-water multifunctional pipeline repair machinery

Based on investigation on deep-water pipeline maintenance and repair experiences in other countries, the concept of deep-water multifunctional pipeline repair machinery was proposed. In addition, overall structure of the machinery was clarified and the prototype was designed. See Fig. 3 for 3D structure model of the prototype. Generally, the machinery is composed of three packages of power heads, rotary cutting heads, racks, clamping devices, hydraulic valve cabins, underwater control systems, ROV connecting devices, buoyancy materials and other components.

By using two packages of clamping devices, the machinery can secure itself on the pipeline to be processed. The cutting

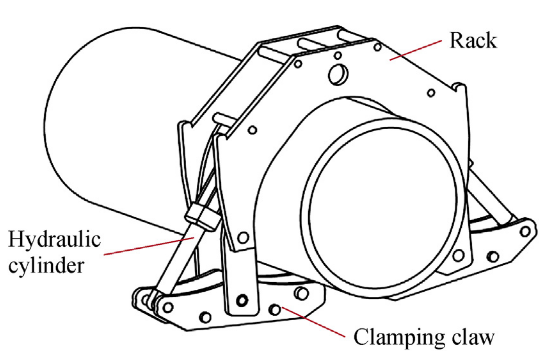

Fig. 1. A pipeline clamping device with “two-arm holding”.

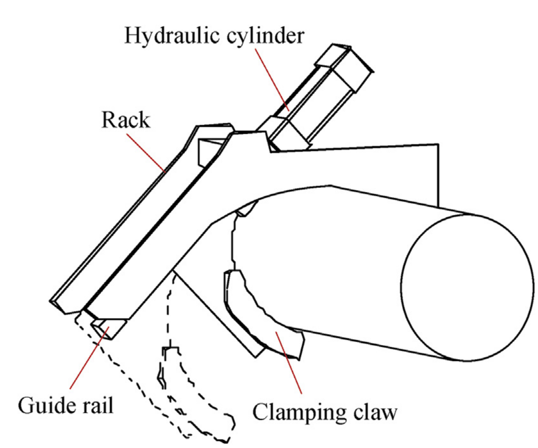

Fig. 2. A pipeline clamping device with “one-arm holding”.