Measurement 94 (2016) 873–882

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Measurement method and pipe wall misalignment adjustment algorithm of the pipe butting machine

Liquan Wang [a], Feihong Yun [a,*], Shaoming Yao [b], Jun Liu [a]

[a] College of Mechanical and Electrical Engineering, Harbin Engineering University, Harbin 150001, China
[b] Advanced Manufacturing Research Centre with Boeing, The University of Sheffield, Sheffield S60 5TZ, UK

ARTICLE INFO

Article history:
Received 29 September 2015
Received in revised form 12 September 2016
Accepted 19 September 2016
Available online 21 September 2016

Keywords:
Pipe butting machine
Pipe measurement method
Three-claw centring
Pipe wall misalignment adjustment algorithm
Centre translation algorithm
Uncertainty

ABSTRACT

This paper presents a runout measurement method and a novel finite grouping method to predict and optimize the rotational angle and translational displacement of butting pipes to minimize pipe wall misalignment (PWM). This study develops a method to minimize the PWM of the pipes excluding the positions of welding seams. In this method, the measurement data are divided into finite groups and the criteria are created to identify the positions of welding seams and eliminate the effect of the welding seams. Finally, the rotational angle and translational displacement of the butting pipes are optimized to minimize the PWM. A butting machine is designed to implement this method. The machine is benchmarked by a standard smooth pipe to minimize system errors. Three butting experiments have been performed with welded pipes of diameter 406 mm. The comparison shows that the computation results agree with the experimental results very well. The maximum PWMs in three experiments are less than 1.87 mm, which satisfies the butting requirements, that is, a PWM of less than 2.0 mm. Then, the uncertainties of the measurement results are discussed.

1. Introduction

Butting accuracy is essential for pipeline connections in offshore oil engineering [1–4]. In the butting of pipelines, the angle between the adjacent longitudinal welding seams of two pipes must be within 90–180° and pipe wall misalignment (PWM) must less than 2 mm [5]. In recent years, pipeline butting machines have been widely researched to achieve minimum cost and maximum flexibility with simple operation and maintenance. It is not very difficult to automate the positioning, centring, locking, and PWM adjustment of pipes. Pipe measurement, data processing, and PWM adjustment are real challenges that significantly affect machine performance. The PWM algorithm of pipeline butting machines performs measurement data processing, data comparison, and PWM evaluation to adjust the pipe centre.

One of the most interesting challenges is the method to minimize PWM [6–8]. The main tools used in oil pipeline welding are internal and external centring devices. In [9–11], an internal adjustment method was used. This method requires an internal centring device that engages the inner surface of the pipes and is primarily driven by hydraumatic or pneumatic processes. The tensioners on the device expand along the radial direction at the butting position to hold the inner surface of pipes and make two pipes concentric. In [12–18], the authors used external centring devices for the same purpose. In [12–15], the pipes were aligned by pipe clamps, in which a hydraulic cylinder produces clamping forces. The multi-jaw clamps hold the pipes at the same position of the circumference to produce the same deformation at the ends of the two pipes. In [16–18], a chain-like device was used for pipe alignment. Each section of the chain is composed of a press block and fine adjustment mechanism. By mechanical adjustments, the chain can be locked and the two pipes are tightly held in a concentric manner.

This paper demonstrates a new method for pipe butting without changing the shape of the pipes to make the pipe butting more accurate and efficient. A pipe butting machine has been developed for this challenging purpose. The measurement process has been modelled and a method has been developed for data processing to optimize the path routine of the centre adjustment. Then, a PWM adjustment algorithm has been constructed to determine the required rotational angle and the translational distance of the two pipes. Experiments show that the measurement method and PWM adjustment algorithm work well in the pipe butting process.

* Corresponding author.
E-mail address: yunfeihong@hrbeu.edu.cn (F. Yun).

http://dx.doi.org/10.1016/j.measurement.2016.09.034
0263-2241/

2. System design

Fig. 1 shows the steel pipe butting machine system, which consists of a base, feeding mechanism, gantries, an unloading mechanism, a preheater, displacement sensors (laser type), and an industrial control computer. Four gantries are mounted on the base, which are arranged in two groups. The pipes are transferred onto the gantries by the feeding mechanism, the displacement sensors inspect the pipes' outer diameter, and the gantries adjust the pipes' position according to the inspection result. Then, the pipes can be welded after preheating. After the pipes are welded, the unloading mechanism will pull the butted pipes out of the system. The gantries are the critical units of the system and the functional accessories are settled on or around them to implement the related tasks [19].

Fig. 2 shows the structure of the gantry. Three claws on each gantry comprise a three-claw centring system to hold the pipes. The three-claw centring system is installed on a turntable so that it can rotate together with the turntable. The rotations of the four gantries' turntables can be controlled synchronously, separately, or in two groups. Each turntable on the four gantries is equipped with a motor and an absolute optical encoder for real-time feedback control [20–22] of the turntable.

Every claw of the three-claw centring system has a single-degree-of-freedom movement towards or away from the centre of the turntable. The accuracy of this chuck is controlled at a reasonable level [23]. The rack and pinion mechanism ensures accurate displacement of the gantries on the frame base. The gantries hold two pipes and move to the measurement position so that the sensors can measure the pipes' outer diameters while the turntables are rotating. The industrial control computer is an interactive terminal [24]. It will control the mechanical system, process the data acquired by the displacement sensors, and display the related results.

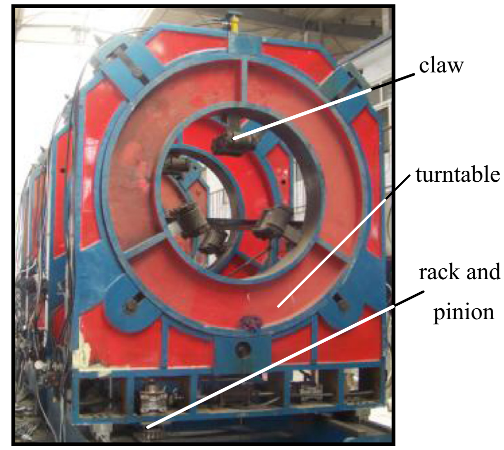

Fig. 2. Gantry structure.

3. Measurement method and data processing

3.1. Mathematical model of displacement measurements

As shown in Fig. 3, the measurement of the two pipes is the foundation of the overall method. Fig. 4(a) demonstrates the runout measurement method [25–29]. Two pipes are held by the gantries. Two sensors are installed on the same line at the same height with the same incidence angle, which will minimize errors of the gantry mechanical system. Sensor 1 and Sensor 2 perform measurements for Pipe 1 and Pipe 2, respectively, rotating at the same speed and at a given frequency.

Let us consider Pipe 1 as an example. The rotating speed of the turntable motor is 600.0 rpm. The transmission ratio between the motor and turntable is 306.0. Pipe 1 rotates with the turntables at an angular speed of $\omega = 11.76°/\text{s}$. A constant measurement frequency is defined to obtain equally spaced measurement points on the circumference. The interval angle of the measurement points is θ_{relative}, the number of points is J, and their relationship is given by $J = 2\pi/\theta_{\text{relative}}$. Given $J = 920$, θ_{relative} will be 0.3913° and the corresponding motor angle, $\theta_{\text{relative-motor}}$, is $306.0 \cdot \theta_{\text{relative}} = 119.7°$. The absolute optical encoder feeds back the angular displacement of the motor at real time with an accuracy of ±0.5″. The control system sets the encoders' zero point. In this case, the motors are controlled by a multi-motor synchronous control module [30,31]. The maximum deviation of the encoders is less than 0.0017° in the experiments and the relative error is 0.00142%.

To perform the measurement within a stable rotation period, the pipes will rotate three revolutions and the measurement will take place in the second revolution. When the pipes' rotation number is 2, the control system will record the data acquired from Sensor 1. The data are denoted as $s_{1,1}$ and the rotational angle as θ_1, which stands for the angle of the first point. This system keeps recording until the pipes' rotation number is 3. The distance and angle data of Pipe 2 can be obtained in the same way.

As shown in Fig. 4(b), the measurement data of the two pipes are

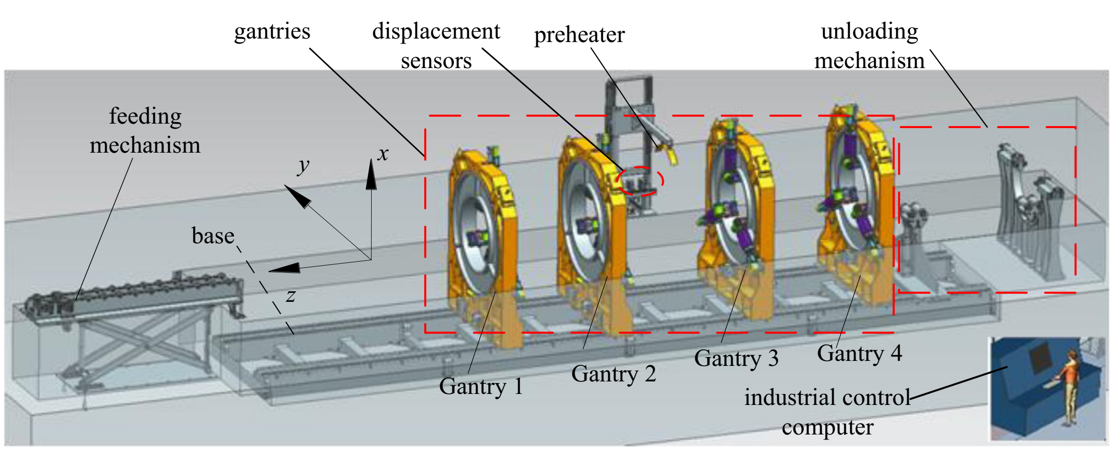

Fig. 1. Schematic of the steel pipe butting machine system.