Vibration testing and processing technology optimization of groove machine for large diameter oil and gas pipeline

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Abstract—The shape modulating machine for the large-diameter oil & gas pipeline is the main component of the automatic welding equipment of oil & gas pipelines, and is mainly used for pipe processing groove at the construction site. The groove quality of the pipe end directly affects the difficulty and quality of automatic welding. Engineering application shows that one of the main factors affecting the quality of pipe groove processing is the mechanical vibration of the shape modulating machine. Taking the CPP900-FM4048 shape modulating machine produced by Pipeline Science Research Institute Co., Ltd as the research object of the study, analyzing the vibration test under different working conditions, finding out the main vibration source and analyzing the cause of vibration main frequency components. The feed pressure, tension pressure, cutter velocity, feed rate and tool arrangement during groove machining are optimized and precisely controlled to improve the accuracy of the pipe groove.

1. INTRODUCTION
Since 2016, with the improvement of the pipeline construction quality requirements, a large number of pipeline projects, such as China-Russia crude oil phase ii, China-Russia eastern line, the Yunnan-Vietnam line and the TangShan LNG external pipeline, have started to adopt automatic welding for girth welding of pipelines extensively. The significant features of automatic pipe welding are low labor intensity of welding works, high welding efficiency and easy to ensure the welding quality, especially in the welding of large-diameter Thick-Wall pipelines. The complete set of automatic pipeline welding equipment consists of the shape modulating machine (also known as pipe facing machine), pipe internal welding machine and pipe external welding machine \cite{1, 2}. Pipe end beveling is the first step of automatic pipe welding. The quality of pipe end beveling directly affects the difficulty of the pipe counterpart and the quality of automatic welding. Therefore, it is necessary to
control the pipe groove processing from the aspects of the groove processing equipment, groove cutting process parameters and other aspects to obtain the requirements of the pipe automatic welding on groove angle, tubesheet plane degree, blunt edge width and the surface roughness.

2. COMPOSITION AND WORKING STATE OF SHAPE MODULATING MACHINE
The shape modulating machine is mainly composed of tensioning mechanism, main driving device, cutter head, floating knife seat, cutting tool and directive wheel system, and hydraulic pump station (Figure 1) [3]. Through the hydraulic cylinder and linkage mechanism, the tensioning mechanism tightens the harmogegathy boot into the inner wall of the pipe end to fix the entire equipment. The main driving device drives the cutter head to circle cutting groove through the hydraulic motor, the feed hydraulic cylinder provides feeding force. The floating knife seat, tool and directive wheel are used for cutting groove. Under the pressure of cutter head spring, the cutting roller closed into the inner wall of pipeline to adapt to the change of pipeline ellipticity and achieve copying cutting [4, 5]. The hydraulic pump station powers the whole system.

Figure 1. Physical diagram of CPP900-FM4048 the shape modulating machine

3. THE MAIN FACTORS AFFECTING THE QUALITY OF PIPE END GROOVE
According to the structure, working principle, working state and a large number of on-site groove processing experience, the main factors affecting the quality of pipe end groove are as follows.
- The ellipticity of the orifice.
- The rigidity and stability of the shape modulating machine.
- Forced state and mechanical vibration of the shape modulating machine.
- Installation and adjustment accuracy of cutting tools.
- Working parameters during groove processing, such as tension, rotational speed, feed rate, etc.

The ellipticity of the orifice needs to be precisely controlled by the steel pipe manufacturer, and the installation and adjustment of the cutting props are controlled by the on-site construction workers. Through the pipe end groove shaping machine vibration test, this paper find out the main vibration source and analyze the main vibration frequency components, optimize and determine the groove processing working parameters, improve the groove quality, efficiency and pass rate.

4. THE SHAPE MODULATING MACHINE VIBRATION MEASUREMENT AND ANALYSIS

4.1. Test Instrument
SINOCERA YE6231 Dynamic Measuring Vibration Test and analysis system was used for data acquisition and data analysis was performed in conjunction with Matlab. The sensor adopts the piezoelectric vibration acceleration sensor of Kisler and SINOCERA company to pick up the vibration signals of different measuring points of the facing machine. The relevant test instruments are shown in Figure 2.
4.2. Measuring point arrangement
Three measuring points were set up for the motor, box and reducer with large vibration.

4.3. Test data and results analysis
The analysis of vibration signals is generally conducted in time domain and frequency domain, which are two observation methods for vibration analog signals[6]. Time domain analysis is based on the time axis as the coordinate to represent the dynamic signal relationship, frequency domain analysis
change the signal into the frequency axis as the coordinate to express. They are interrelated and complement each other to reveal the law of mechanical vibration together. An image that describes signal as a function of time is called time domain diagram, and analyzing the signal in the time domain is called time domain analysis. The main parameter index of time domain analysis is root mean square value, also known as the effective value of signal, which can reflect the signal energy as a whole. The main parameter of frequency domain analysis is frequency, which indicates how fast the object vibrates. The unit is times per second, also known as Hertz.

4.3.1. Effect of rotating velocity on vibration

4.3.1.1. Time domain analysis

![Comparison diagram of root mean square value of different rotating velocity (supply 0.2 mm/r)](image)

Table 1. Statistical table of root mean square value (unit m/s²)

| Test Position | 25r/min no-load | 25r/min cutting | 33r/min cutting | 39r/min no-load | 39r/min cutting |
|---------------|----------------|----------------|----------------|----------------|----------------|
| Motor         | 5.4            | 5.3            | 6.8            | 5.2            | 5.4            |
| Box           | 4.6            | 4.5            | 4.8            | 4.4            | 4.9            |
| Reducer       | 2.8            | 4.5            | 8.8            | 3.1            | 7.3            |

From the Figure 5 and Table 1, we can conclude that:

- Under no-load conditions, the root-mean-square value of the reducer is the smallest and the RMS value of the motor is the largest. The rigidity and stability of the shape modulating machine.
- Under the cutting condition with a rotation speed of 33r/min, RMS value of the motor and reducer is large, and the RMS value of the reducer is the largest.
- During rotating velocity changing from 25r/min to 39r/min with load, the RMS value of both motor and reducer increases first and then decreases. In addition, the RMS value of reducer is the largest, which means the contribution is the largest and the box’s RMS value is the smallest.
- Under all working conditions, the root-mean-square value of the box varies from 4.4 to 4.9 m/s², and the overall variation range is small, which means the box is not the main vibration source.

In summary, from the perspective of the time domain, it can be concluded that the reducer is the main vibration source that causes vibration increase.
4.3.1.2. Frequency domain analysis

Figure 6: Spectrum diagram of 0-50Hz at different rotating velocity (supply 0.2mm/r)

Cutting vibration will affect the processing quality of the surface. For pipe groove processing, low-frequency vibration mainly affects the groove quality of the machine, and it will cause the wavy grain production on the processing surface [7]. The three measuring points are 25r/min, 33r/min, and 39r/min during normal cutting when the feed rate is 0.2mm/r. It can be seen from the frequency domain waveform diagram when the vibration frequency range from 0 to 50 Hz:

- The frequency component of the reducer is more complex than that of the motor and the box, and the amplitude is higher. The highest value is at the velocity of 33 r/min, and the root-mean-square value is 0.4m/s².
- At the rotation velocity of 33 r/min, the main frequency components are 0.1Hz, 0.6Hz, 4.5Hz, 13.9Hz, 23.2Hz, and 37.1Hz. At the rotation velocity of 25 r/min, the main frequency components are 0.1Hz, 1.2 Hz, 5.3Hz, 10.6 Hz, 17.7 Hz, 23.1Hz, 28.4Hz. When the rotation velocity is 39r/min, the main frequency components are 5.3Hz, 12.3 Hz, 17Hz, 28.4 Hz, 36.9Hz, 42.6Hz and 45.4 Hz.

4.3.2. Effect of feeding rate on vibration

4.3.2.1. Time domain analysis

Figure 7: The trend comparison of root mean square value with the change of feed quantity at three measuring points

It can be concluded from Figure7 that the root-mean-square value of the three measuring points increases first and then decreases with the increase of the feed rate. The reducer's RMS value is the largest which has more larger variation range, the change range of the box and the motor is relatively
flat, and the box’s RMS value is the smallest. The vibration of reducer is larger and the vibration of box body is smallest.

4.3.2.2. Frequency domain analysis

Combined with the root-mean-square value obtained with the change of feed rate, the signals with different feed rate were analyzed in sections, and the frequency domain waveforms of the three feed points under different feed conditions are obtained, as shown in Figure 8, 9 and 10. It can be seen that the frequency amplitude of the reducer is significantly higher than that of the motor and the box. The frequency amplitude of the reducer increased first and then decreased with the feed rate increasing from 0.15mm/r to 0.35mm/r. The main vibration frequency components are 18Hz, 28Hz and 45Hz.

Figure 8. Frequency domain diagram of the feed changing amount

Figure 9. Frequency domain diagram of the box changing with feed amount

Figure 10. Frequency domain diagram of reducer changing with feed amount
5. **OPTIMIZATION OF GROOVE PROCESSING**

Through the vibration test of shape modulating machine, it is found that the reducer is the main vibration source. In order to reduce the impact of the reducer’s vibration on the processing quality of groove, it can be solved by optimizing the fixed support structure of the reducer, replacing the smoother reducer and optimizing the processing parameters of groove. The vibration test results show that the suitable combination of groove processing parameters can control the vibration of reducer and the shape modulating machine within a reasonable range, and it is easy to obtain a qualified groove.

| The serial number | Project             | Operation parameters | Checking methods        |
|-------------------|---------------------|----------------------|-------------------------|
| 1                 | Tight pressure      | 10-12MPa             | Pressure gauge          |
| 2                 | Feed pressure       | 3-4MPa               | Pressure gauge          |
| 3                 | Rotary cutting      | 18-20MPa             | Pressure gauge          |
| 4                 | Equipment lifting   | 2 t                  | Vertical displacement   |
| 5                 | Cutting speed       | 18-15r/min           | Visual count            |
| 6                 | Feed                | 0.15-0.25mm/r        | Vernier caliper         |
| 7                 | Cutter layout       | 4 knife evenly       | Visual count            |
|                   |                     | distributed          |                         |

6. **CONCLUSION**

According to the vibration analysis under different working conditions, the main vibration source of CPP900-FM4048 pipe end groove shaping machine is reducer, and the main vibration frequency components are 18Hz, 28Hz and 45Hz. The effect of low frequency vibration on groove quality is mainly caused by low frequency vibration. Through vibration test, the range and control method of tool layout, feed quantity, rotation speed, feed force and tensioning force during groove processing are given, and the precision of pipe groove is improved.

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