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THE EFFECT OF JOINT MOVEMENT ON THE NATURE FREQUENCIES OF TRANSMISSION LINE INSPECTION ROBOT

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Abstract: - The difference in natural frequencies of the transmission line inspection robot between maintaining fixed posture and moving up to corresponding typical posture at the working speed is explored by means of modal experiment. First a double-arm symmetrical suspension mobile robot developed for autonomous full-path hotline inspection along 220kV phase conductor is presented, then the modal tests are performed respectively under both conditions that the robot arm is fixed in and moved up to three typical postures at the working velocity. Through comparison on low-order nature frequencies under two conditions, the relation between the robot's joint kinematic parameters and dynamic characteristics is identified: the slight decline of joint stiffness declines under motion state has whereby result in the reduction of natural frequencies.

Key-Words: Inspection Robot; natural frequencies; joint movement; modal experiment; motion state; stationary state; transmission line

1 Introduction

Transmission line inspection robot (hereinafter referred to as Inspection Robot) is a new type of technical platform for hotline inspection of high-voltage transmission line, which is able to detect mechanical and electrical failures of transmission lines and inspect their safety passages with detection instruments. In the developed countries like Japan, Canada and USA, research on overhanging transmission-line inspection robot has been carried out since the 1980s [1]-[6]. In recent years, China has made some great achievements in related fields[7]-[11], however, most of which are focused on mechanism and control of the inspection robots, no study regarding their dynamic characteristic has been reported till present.

Inspection Robot, as a mobile technical carrier for inspection of transmission line, is required to carry various inspection instruments and travel along full path of overhead transmission line, including traveling along phase conductor and surmounting obstacles (e.g. damper, pressing duct, clamp and insulator chain) as well as transferring from phase conductor to jumper in the event of spanning angle tower, which is shown in Fig.1.

During surmounting obstacles and transferring path, such robot is required to adjust posture based on working conditions and the drive motor of each joint is subject to frequently start/brake and accelerated/decelerated running. Therefore, its dynamic characteristic is of great importance, which has direct effect on precision of motion control, fault signal detection and location.

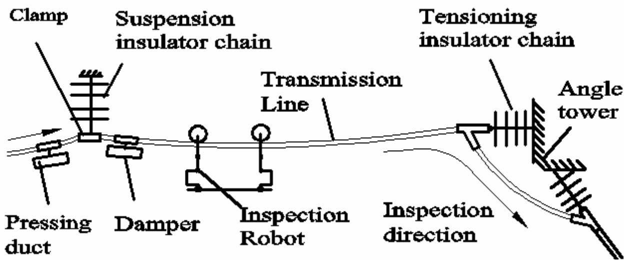


Fig.1: Structure of Inspection Path

Natural frequencies of the robotare the most important parameter to evaluate its dynamic performance. The dynamic characteristic of inspection robot under working state is relevant to its posture, structure parameters, materials parameters, and joint kinematic parameters. There is a difference between the dynamic characteristic parameters of robot in a certain posture and the instantaneous dynamic characteristic in the event that the robot arm is adjusted to such posture through joint movement.

In the literatures [12], the dynamic characteristic of an inspection robot developed by Wuhan University for autonomous hotline inspection along 220kV phase conductor is analyzed in case of being fixed into four typical postures. Herein, on above mentioned basis, the modal experiment further proceeds on three typical postures of the robot under motion state for the purpose of analyzing the effect of joint movement of the inspection robots on their natural frequencies.

2 Typical Postures of Model Analysis

In consideration of the transmission-line structure and the requirement of inspection, the inspection robot is designed into double-arms symmetrical and suspending structure, as shown in Fig.2.

Either of the two robot arms has one roller on the end enabling the robot to roll along non-obstacle section of transmission line; there is a relative-motion degree of freedom between two arms available for their interactive sliding and transposition of both arms along guide rail. Either robot arm has two rotation degrees of freedom for rotation of robot arms on vertical axes Ⅰ and horizontal axes Ⅱ. Each joint is independently driven by a motor. Through programming of four basic actions mentioned above, full path inspection along overhead transmission line can be realized, including rolling along non-obstacle line, surmounting obstacles, and path transferring.

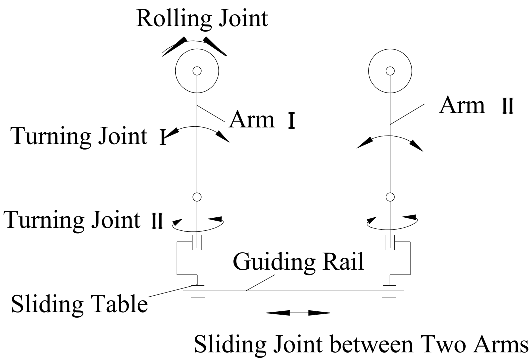


Fig. 2: Diagram of inspection robot prototype Ⅲ

There are 5 typical postures during inspection, however, in terms of symmetrical structure, only 3 are selective for model analysis as follows, which are shown in Fig. 3 (a), (b), (c) respectively:

Posture 1: Normal opening of double arms，Arm I suspending and clamping the conductor, forming an angle of 120° with Guiding Rail.

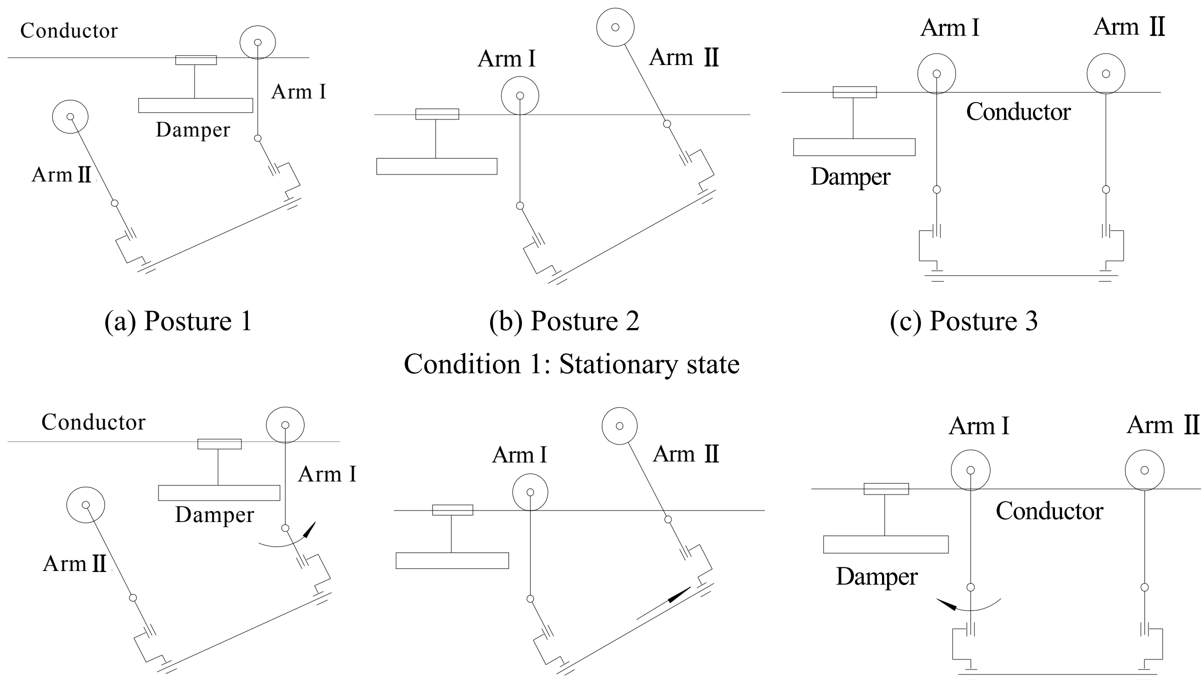
Posture 2: Normal opening of double arms, Arm I suspending and clamping the conductor, forming an angle of 60° with Guiding Rail.

Posture 3: Normal opening of double arms in parallel, Arm I suspending and clamping the conductor.

Then, the modal experiment conditions under motion state are defined as follows, which are shown in Fig. 3 (d), (e), (f) respectively:

1） Arm Ⅰsuspending and clamping conductor, Arm Ⅱ and robot body anticlockwise rotating around Turning JointⅠ of Arm Ⅰto posture 1;

2） Arm Ⅰsuspending and clamping the conductor,



(a) Posture 1 (b) Posture 2 (c) Posture 3

Condition 1: Stationary state

(d) Posture 1 (e) Posture 2 (f) Posture 3

Condition 2: Motion state

Fig. 3: Typical postures for model analysis

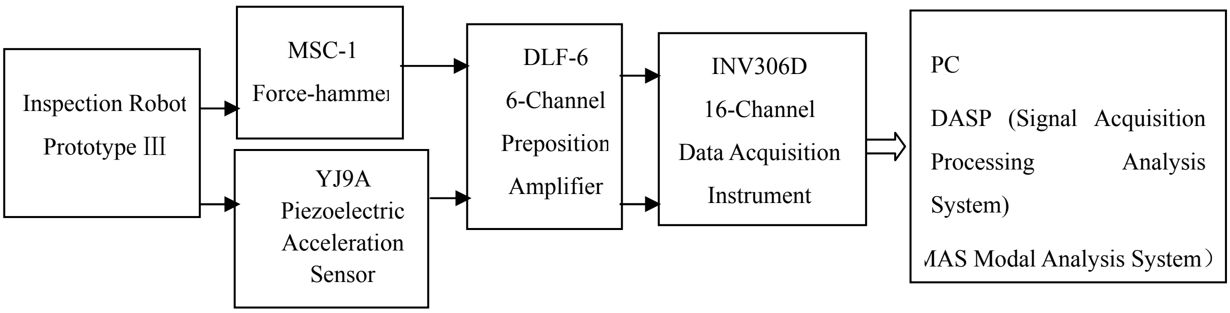


Fig. 4: Composition of modal experimental test system

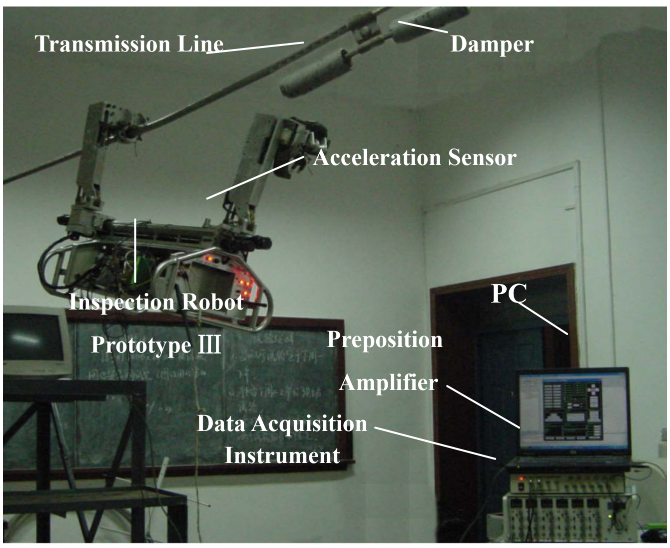


Fig. 5: Testing Field

Arm Ⅱ sliding along the guiding rail to posture 2

3） Arm Ⅰ suspending and clamping conductor, Arm Ⅱ and robot body clockwise rotating around Turning Joint Ⅰ of Arm Ⅰ to posture 3

The joint movement velocity in condition 2 experiment is identical with that in normal inspection working state.

3 Modal Experiment

3. 1 Experimental method and test system composition

The method of impulse excitation is adopted for modal experiment. We apply exciting force on multiple points in turn and collect response signal from a single point.

The test system is composed of INV306D 16-Channel Data Collector, MSC-1 Excitation Force-hammer, YJ9A Piezoelectric Acceleration Sensor, DLF-6 6-Channel Filter Amplifier, which is shown in Fig.4, of which the force-hammer excitation signal connecting Channel 1 and the vibration response signal connecting Channel 2.

Here, DASP is available for data acquisition processing and analysis, and MAS is available for modal analysis.

3.2 Measuring points layout and excitation scheme

In consideration of mechanism features of the inspection robot, eight measuring points are selected on two robot arms respectively, and twelve points are selected along guide rail respectively and totaling 28 points are arranged shown in Fig.4. Force-hammer is used for applying exciting force on Y-Z plane in turn and response signal is collected on Y direction of the measuring point at the 12th testing point. We excited each point thrice, and then performed linear averaging on data to decrease the testing error.

3.3 Setting of test parameters

DASP offers a Varied-Time-Base (VTB) sampling method suitable for modal test, i.e. sampling frequency of Channel 1 and any rest channels of collector can be set into a certain multiplying relation accordingly. Sampling frequency for impulse excitation force is set to be four times of that for vibration response.

Sampling frequency of impulse excitation force (Channel 1): 10,000HZ

Sampling frequency of vibration response (Channel 2): 2,500HZ

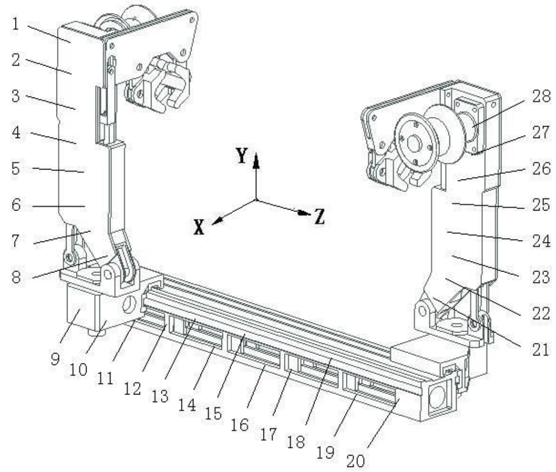
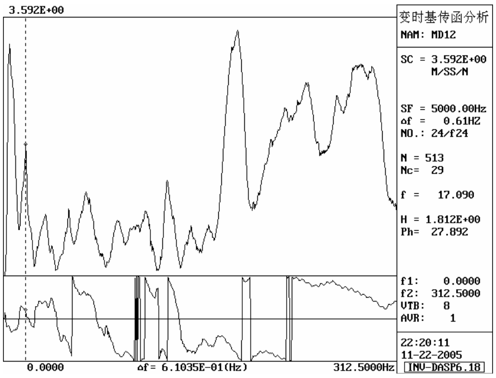


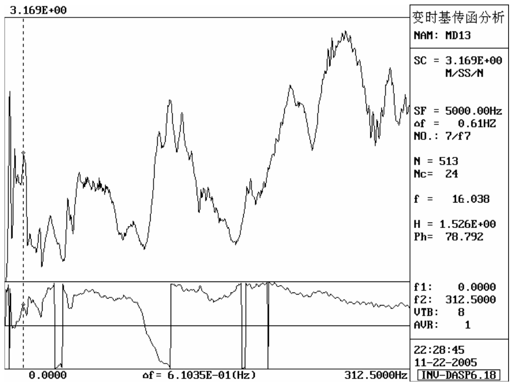
Fig. 6: Testing points layout

Table 1: Natural frequency of 3 postures under 2 conditions

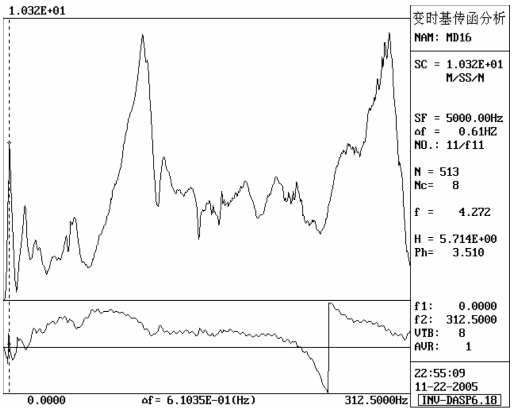
Ordering	Frequency (Hz)					
	Posture 1		Posture 2		Posture 3	
	Stationary State	Motion State	Stationary State	Motion State	Stationary state	Motion State
1	3.465	3.169	4.272	3.659	3.662	3.352
2	7.573	7.024	8.906	8.201	7.935	7.324
3	17.09	16.04	19.98	18.97	18.96	17.70



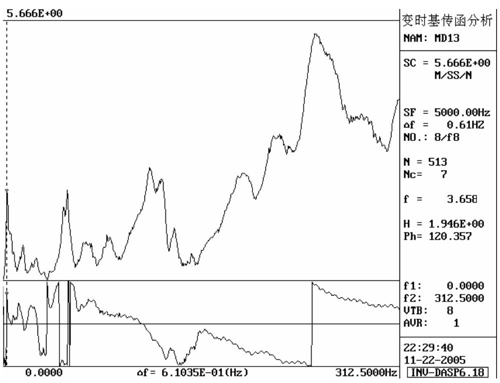
(a) Posture 1 under stationary state



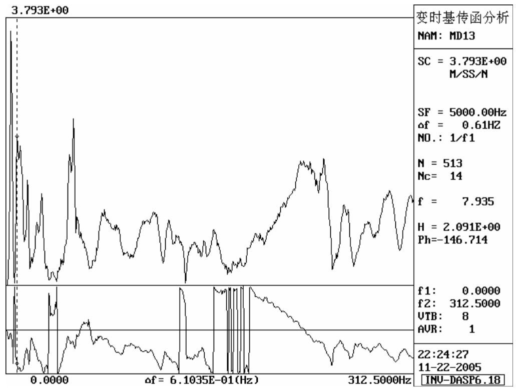
(b) Posture 1 under motion State



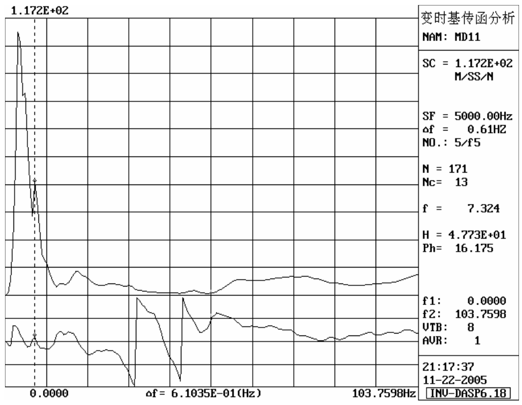
(c) Posture 2 under stationary state



(d) Posture 2 under motion state



(e) Posture 3 under stationary state



(f) Posture 3 under motion State

Fig. 7: Amplitude-frequency Characteristic Curve of the 16th measuring point on Y-Z plane

4 Results of Modal Experiment

Through transfer function analysis on the impulse force excitation and the vibration response signals of the inspection robot, and averaging on transfer function of each measuring point, low order modal frequencies parameters are determined and corresponding mode shapes is obtained.

The Amplitude-frequency Characteristic Curve of the 16th measuring point under fixed condition and motion condition Group 1 are shown in Fig.6. The natural frequencies of the three foremost modes are listed in Table 1.

5 Analysis and Conclusion

It is known based on comparison of frequencies of the three low order models under both conditions as follows :

In three postures, all natural frequencies in stationary state are higher than those in motion state; In three postures, with regard to first order bend frequencies on XY plane readily observed, the discrepancies with those in stationary state and in motion state is approximately 8%~12%.

It is whereby infered that the joint stiffness, which will decrease at motion state, is the foremost effect of the robot natural frequencies.

Acknowledgement

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