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KINEMATICS AND DYNAMICS SIMULATION OF INSPECTION ROBOT FOR POWER TRANSMISSION LINE

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Abstract: -Kinematics and dynamics simulation of a double-arms mobile inspection robot for 220kV overhead high-voltage transmission line is performed based on virtual prototyping technology. Modeling and simulation research of inspection robot in task environment are carried out with UG three-dimensional solid modeling function and ADAMS dynamics simulation function. Based on the simulation result, the relationship between joint movement, track of the inspection robot arm end, and joint driving moment is attained. Therefore, the research result provides theoretical basis for the inspection robot's motion programming.

Key-Words: - Inspection robot, Virtual prototype, Kinematics, Dynamics, Simulation

1. Introduction

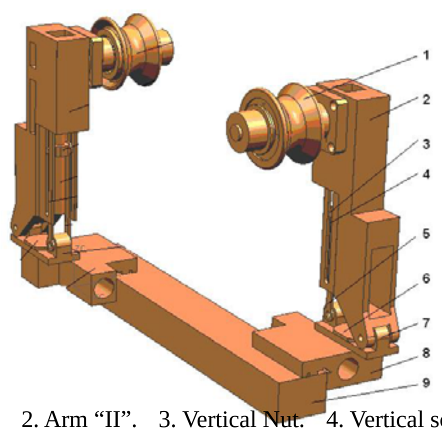
Inspection robots suspending on transmission line inspect mechanical/electrical fault of transmission line and related passage, with transmission lines as their traveling/working path by means of remote control/auto control. As required by particular task environment, robots are capable of traveling along whole transmission line including rolling/creeping along straight line segment and tensioning line segment, and surmounting barrier such as suspending clamp, insulator, and damper.

This Paper introduces virtual prototype technology into kinematics and dynamics simulation of inspection robot mechanism, performs a frontier research on kinematics and dynamics modeling and simulation of inspection robot's on-line work in combination with UG[1] three-dimensional solid modeling function and ADAMS[2] dynamics simulation function, and attains the input/output relation between joint movement and end track of inspection robot, as well as the law governing the influence from robots system and transmission line on their dynamics.

2. Solid Modeling

The robot is of symmetric structure, both arms of which can swing and slide on vertical plane and rotate on horizontal plane respectively.

In UG environment, models of all robot parts were created and then virtual prototype of the inspection robot was assembled. Here, Boolean calculation is available for incorporating all parts with no relative movement into a solid model for the purpose of improving simulation rate. See Fig. 1—an assembling model of inspection robot in UG.



1. Roller. 2. Arm "II". 3. Vertical Nut. 4. Vertical screw rod. 5. Draw bar. 6. Rotation axis. 7. Rotating table.

8. Sliding table. 9. Guide rail.

Fig. 1: An assembling model of inspection robot

We Created a Transmission line-Suspension Insulator Model [3] equivalent to physical model of laboratory transmission line, as shown in Fig.4. In this paper, robot and the working environment model was divided into two groups:

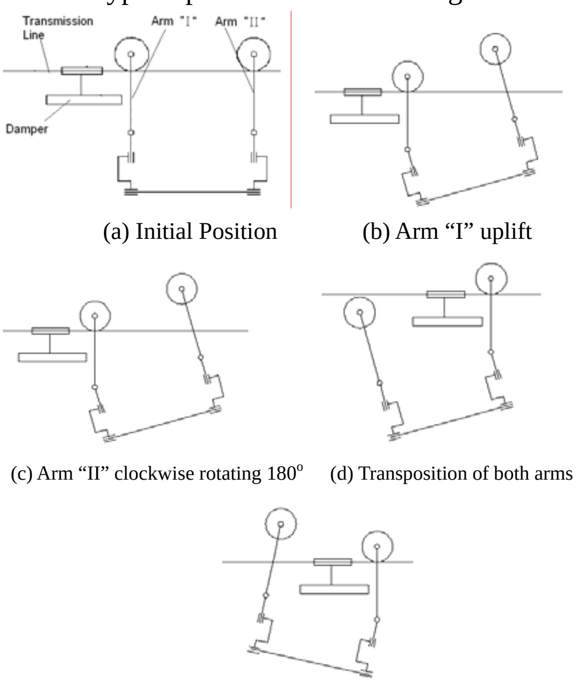
Group 1: Regarding transmission line model as rigid, performing kinematics simulation on inspection robot's passing suspension insulator chain and analyzing whether inspection robot can succeed in spanning a barrier.

Group 2: Regarding non-barrier segment of a transmission line as flexible and analyzing dynamics character of the robot.

3. Kinematics Simulation of Inspection Robot

3.1 Programming barrier-passing action

Inspection robot's spanning a barrier consisted of basic actions as follows: Single arm uplift I, Single arm rotating 180°, Transposition of Arm "I" and Arm "II" along guide rail, and single arm descending. Several typical poses were listed in Fig. 2.



(a) Initial Position (b) Arm "I" uplift

(c) Arm "II" clockwise rotating 180° (d) Transposition of both arms

(f) Arm "II" counter-clockwise rotating 180°

Fig. 2 Typical poses for robot's passing barriers

There are differences in structural property between suspension insulator chain and common structural barrier (damper or clamp, etc.), therefore programming actions for inspection robot's surmounting suspension insulator chain will be more complicated than other programming actions.

Collision inspection is so necessary during robot's passing suspension insulator chain as to improve validity of simulation. This Paper defines solid-solid collision between Arm "I" and suspension insulator chain as well as Arm "II" and suspension insulator chain, roller of Arm "I" and suspension insulator chain, and roller of Arm "II" and suspension insulator chain. In this way, collision situation can be observed during simulation.

3.2 Kinematics modeling

In view that the status of restraints between each arm roller and transmission line will change when the robot surmounts barriers, i.e. after the roller of Arm "II" had reached the left side of barriers, fixed it with the transmission line so that the roller of Arm "II" and the transmission line would present perfect restraint status; in the meantime, released the fixed restraint of Arm "I" roller and the transmission line so that Arm "I" roller relative to transmission line would present non-restraint status. So ADAMS script simulation form[4] was adopted.

Joint kinematical function was fit with STEP[5] function. As the paper length restriction, only list the Mot_1_L function. As shown in Figure 3, such function is defined as:

150.0d*(step(time,0,0,1,1)-step(time,17,0,18,1)) -225d*(step(time,91,0,92,1)-step(time,114,0,115 ,1))+150d*(step(time,128,0,129,1)-step(time,145 ,0,146,1))

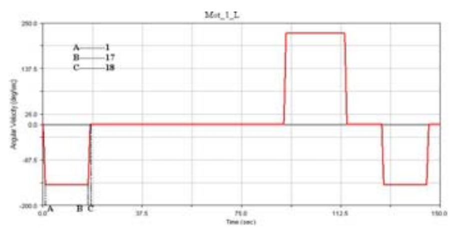


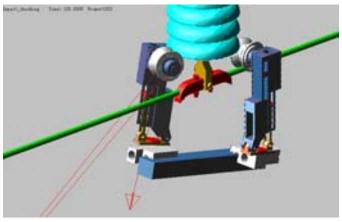
Figure 3 Mot_1_L Rate-Time function

3.3 Simulation result analysis

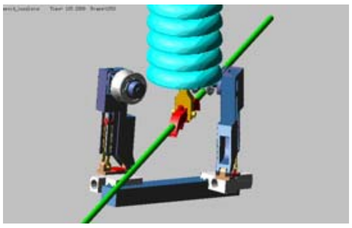
Two groups of joints action programming were adopted for kinematics simulation on inspection robot's surmounting suspension insulator chain. Importing post-processing module of ADAMS and exporting results of two times of simulation respectively in form of animation, we could visually find that: when the robot passed suspension insulator chain by adopting the first group of action programming, collision force was generated but by adopting the second one, collision force was eliminated which met the requirement of passing/dodging barriers.

Fig.4 compares the status of collision and dodging when the robot passes suspension insulator chain. There are three marks of collision force in Fig.4(a): collision between two edges of Arm “II” roller and the left side of suspension insulator chain; collision between sharp corner of Arm “II” closer to one side of roller and suspension insulator chain. But in Fig.4 (b): when the robot reaches the same spatial position indicated in Fig.4 (a), collision is avoided, because the rotation axis on root of Arm “I” and sliding table have rotated for a certain angle.

The kinetic characteristic of each roller’s centroid is shown in Fig.5 and Fig.6.

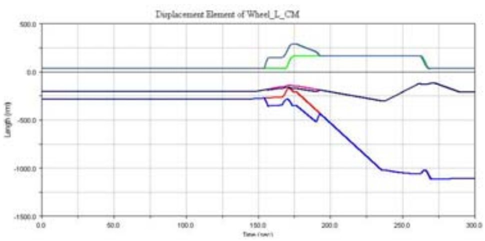


(a) Generation of collision force

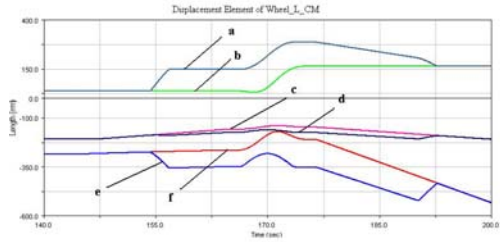


(b) Elimination of collision force

Fig.4 Azimuth I for robot’s passing suspension insulator chain.

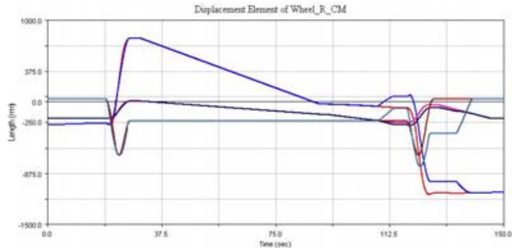


(a) Displacement element in X, Y and Z-direction of Arm “I” roller’s centroid

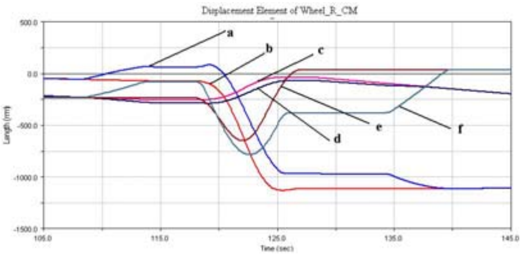


(b) Partial view of displacement element

Fig.5 Displacement-Time curve of Arm “I” roller’s centroid



(a) Displacement element in X, Y and Z-direction of Arm “II” roller’s centroid



(b) Partial view of displacement element

curve a Z-direction displacement element (Programming I) of Arm “I” (“II”) roller’s centroid;

curve b Z-direction displacement element (Programming II) of Arm “I” (“II”) roller’s centroid;

curve c Y-direction displacement element (Programming I) of Arm “I” (“II”) roller’s centroid;

curve d Y-direction displacement element (Programming II) of Arm “I” (“II”) roller’s centroid;

curve e X-direction displacement element (Programming I) of Arm “I” (“II”) roller’s centroid;

curve f X-direction displacement element (Programming II) of Arm “I” (“II”) roller’s centroid.

Fig.6 Displacement-Time curve of Arm “II” roller’s centroid

4. Dynamics Simulation of Inspection Robot

4.1 Transmission line modeling

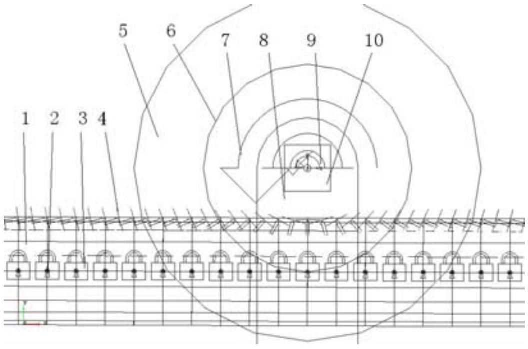
Since the robot took high-voltage transmission lines as its working path, coupling of working environment and robot's multiple-rigid system had great effect on robot dynamics character. Therefore, the flexible transmission line should be considered during modeling. With catenary's formula [6] of transmission line adopted, coordinates of key points on the centerline of transmission line could be attained. And then we created the finite element model for a 10-meter-span transmission line in ADAMS, whose natural frequencies were attained as shown in Table 1.

Table 1 Transmission line modal parameter

Vibration mode (N)	Frequency (Hz)	Vibration mode (N)	Frequency (Hz)
1	1.5	4	7.0
2	4.3	5	8.4
3	4.3	6	11.0

4.2 Contact modeling of transmission line and roller

According to the finite element analysis method [7], it is necessary to realize contact modelling between flexible line and roller through discretizing the actual continuous contact modeling. We simplified the transmission line and roller model reasonably, and equalized their contact force to two dimensional contact between central node group of flexible cord FEA model and rigid roller edge. Dynamics model for inspection robot rolling on non-barrier segment of transmission line contained 300 contract force units in total as shown in Fig.7.



1. Transmission line finite element model. 2. Dumb object. 3. Fixing pair. 4. Contract force unit. 5. Roller of Arm "I". 6. Two-dimensional circle. 7. Kinematical input. 8. Robot body. 9. Rotating pair. 10. Co-planer restraint.

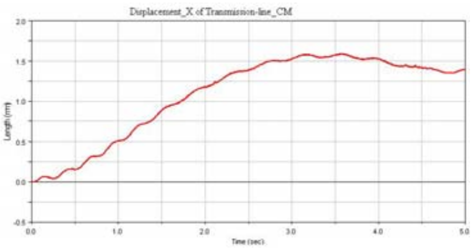
Fig.7 Contract model of roller and flexible transmission line

Motion function of rotating joint between roller and arm-end roller axis was defined by means of STEP function's fitting actual drive of the roller. In STEP function, acceleration time was 0 0.3 second, deceleration time was 4.3 4.6 seconds. With simulation time of 5 seconds and step length of 0.02 second, the motion curves of some parts, joint restraints of the robot and the transmission line was obtained.

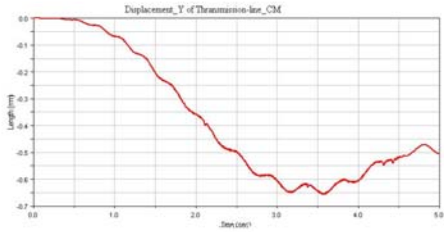
4.3 Example of simulation

4.3.1 Dynamics simulation for rolling along transmission line

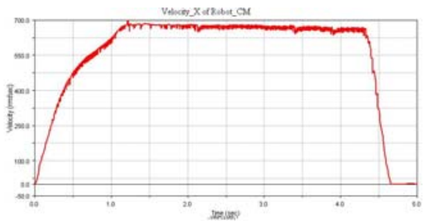
The results of dynamics simulation for robot's rolling along transmission line were shown as Fig.8.



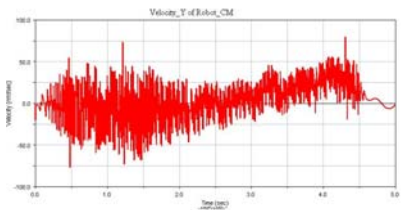
(a) X –direction displacement-time curve of centroid



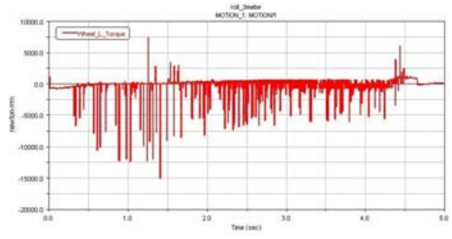
(b) Y–direction displacement-time curve of centroid



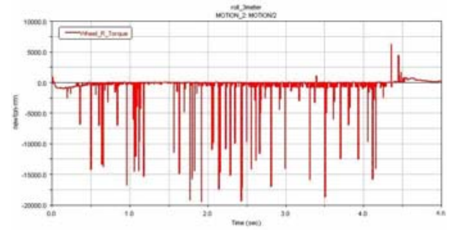
(c) X –direction velocity-time curve of centroid



(d) Y–direction velocity-time curve of centroid



(e) Driving moment of Arm "I" roller



(f) Driving moment of Arm "II" roller

Fig.8 Result of dynamics simulation

4.3.2 Dynamics simulation for Arm "I" uplift

Dynamics simulation for Arm "I" uplift of inspection robot was performed, and two groups of models, i.e. rigid transmission line-robot and flexible transmission line (with finite element model)-robot were created separately to compare and analyze the law governing the influence from different transmission line modeling and different uplift velocity on robot dynamics character.

Robot assembling model was of initial configuration for passing barriers. Only one motor was needed to drive vertical screw rod of Arm "I" and any other active joint was locked during the process of uplifting Arm "I". Therefore, only freedom of such rotating pair should be kept, while other active joint was defined as fixing pair. In addition, finite element model of a 10-meter-span transmission line was quoted to consider and discuss the influence from transmission line flexibility on dynamics solution of uplift action of Arm "I". Rotation velocity (degree per second) of screw rod was fit as ω with STEP function.

Simulation 1: Fixing roller of Arm "I" to ground and defining rotation velocity of Arm "I" vertical screw rod as 1ω;

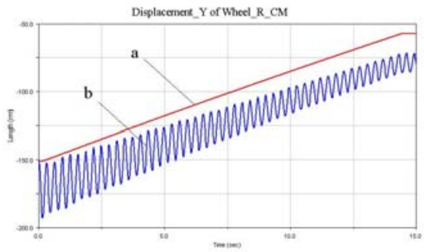
Simulation 2: Activating finite element model of transmission line, fixing arm roller of inspection robot model on transmission line node and defining rotation velocity of Arm "I" vertical screw rod as 1ω;

Simulation 3: Changing rotation velocity of Arm "I" vertical screw rod in Simulation 2 to 1.5ω;

Simulation 4: Changing rotation velocity of Arm "I" vertical screw rod in Simulation 2 to 3ω.

Through the simulation results we can conclude:

(1) Difference of dynamics character of inspection robot between rigid and flexible environment (contrast calculated result of Simulation 1 and 2)



Curve a: Rigid transmission line model;

Curve b: Flexible transmission line model

Fi. 9 Y-direction displacement curve of roller's centroid

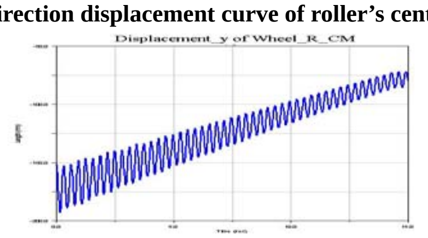


Fig.10 Y-direction displacement curve of Arm "II" roller's centroid

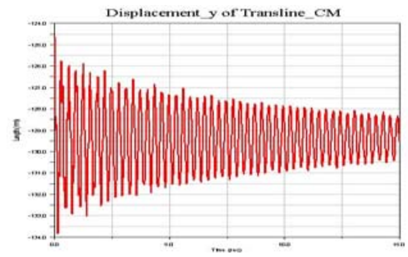
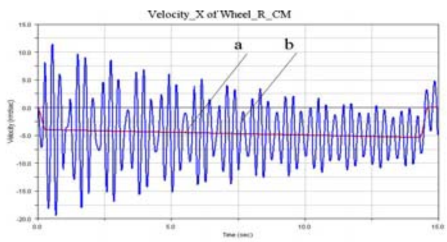
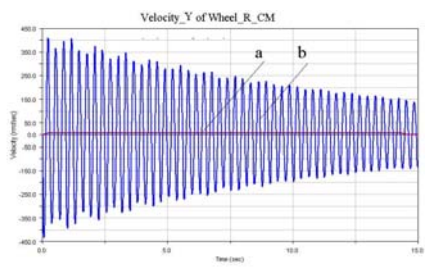


Fig.11 Y-direction displacement curve of transmission line's centroid



(a) X-direction velocity



(b) Y-direction velocity

Curve a: X/Y-direction velocity element of arm “II” roller’s centroid (rigid transmission line)

Curve b: X/Y-direction velocity element of arm “II” roller’s centroid (Flexible transmission line)

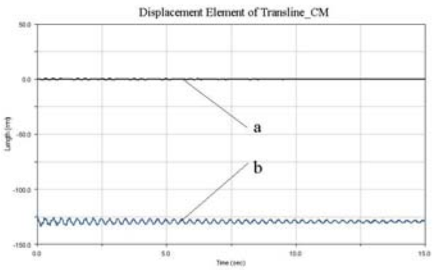
Fig.12 Velocity-time curve of Arm “II” roller’s centroid

In Fig.10: Y-direction displacement curve of Arm “II” roller’s centroid is fluctuating along the centerline and amplitude is attenuated from initial 21mm to 7mm in the end of simulation; In Fig.11: Y-direction displacement curve of transmission line’s centroid finite element model is fluctuating along the centerline and amplitude is attenuated from initial 3mm to 1mm in the end of simulation.

In Fig.12: Curve a is fluctuating along Curve b and fluctuating amplitude of X-direction velocity element curve is attenuated from initial 15mm/sec. to 4.7mm/sec. in the end of simulation; fluctuating amplitude of Y-direction velocity element curve is attenuated from 422mm/sec. to 140mm/sec.

To sum up, in flexible working environment fluctuating amplitude of joint displacement and velocity of robot in start region is more than that in rigid working environment.

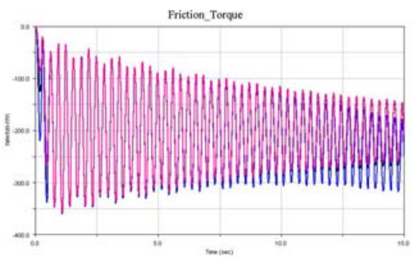
(2) Influence of different Arm “I” uplift velocity on transmission line kinetic character and joint friction force/moment (Contrast calculated result of Simulation 2, 3 and 4)



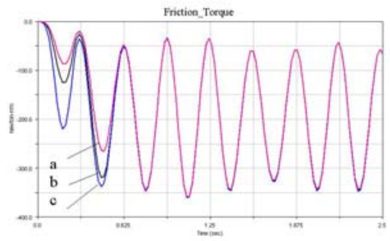
Curve a: X-direction displacement of transmission line centroid

Curve b: Y-direction displacement of Transmission line centroid

Fig.13 Displacement-time curve of transmission line centroid



(a) Friction moment



(b) Partial friction moment

Curve a: Rotation velocity of Arm “I” vertical screw rod is 1ω;

Curve b: Rotation velocity of Arm “I” vertical screw rod is 1.5ω;

Curve c: Rotation velocity of Arm “I” vertical screw rod is 3ω.

Fig.14 Friction moment on root hinging part of Arm “I”

As shown in Fig.13 transmission line centroid is fluctuating at 0.4-mm amplitude in X-direction (horizontal) and 3-mm in Y-direction (vertical), but sum up there is minor variation in amplitude of transmission line centroid. Therefore the motion character of the robot keeps coherence while the arm “I” uplift velocity is different.

Fig.14 is friction moment-time curve between draw bar and rotating table. It is known by comparing simulation data 0.64s ago that the higher acceleration of Arm “I” screw rod is, the greater friction moment on both hinging parts on root of Arm “I” is—when rotation velocity of vertical screw rod is 1ω, 1.5ω, and 3ω, the difference of friction moment of rotating pair between draw bar and rotating table is 96.5N.mm and 38.5N.mm in turn. It is found by comparing data 0.64s later that friction moment will superpose in a while and then diffuse. This is mainly caused by increase of uplift height in turn arising from difference of Arm “I” uplift velocity. This group of friction moment-time curve of rotating pair can be exported as spline-curve, and served as dynamic load input of finite element.

5. Conclusion

This Paper has formed virtual prototype model for inspection robot in UG-ADAMS environment, performed complete analysis on kinematics simulation of robot’s passing suspension insulator chain; created finite element model of transmission line and contact model of roller and transmission line by reference to catenary’s formula of transmission line, conducted dynamics simulation on inspection robot’s rolling along transmission line, and finally completed dynamics simulation on inspection robot's Arm "I" uplift.

Inspection robots and their working environment constitute a quite complicated system model. The models established herein are far from fully demonstrating actuality. They are ready for further improvement: 1) form drive mechanism model of each active joint, especially horizontal screw rod-steel cable-sliding table, so as to factually demonstrate the influence of such drive mechanism on inspection robot system performance; 2) further study dynamics character of each joint in coupling motion.

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