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Dynamics Response of Spatial Parallel Coordinate Measuring Machine with Clearances

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Abstract: In order to grasp the dynamic response of 4-UPS-RPS (four universal joints-prismatic pairs-spherical joints and revolution joints-prismatic pairs-spherical joints) parallel coordinate measuring machine with clearances, a method of dynamic characteristics analysis by using virtual prototyping technology was introduced. The virtual prototype of 4-UPS-RPS parallel coordinate measuring machine with clearances was constructed by ADAMS while the driving limbs, the moving platform and stationary platform of parallel coordinate measuring machine were treated as rigid bodies. Based on the virtual prototype with clearances, the dynamic response, including kinematics output response and contact force of joints element, were obtained. The results of simulation show that the joint clearances are demonstrated to have significant impact on system kinematics and dynamics. This research can provide the important theoretical base of the optimization design and the vibration control for 4-UPS-RPS parallel coordinate measuring machine. *Copyright © 2013 IFSA.*

Keywords: Parallel mechanism, Joint clearance, Dynamic response, Virtual prototype.

1. Introduction

The parallel coordinate measuring machine has advantages of high stiffness, good dynamic performance, no accumulated precision errors, tight construction and strong modularization [1]. As a type of new-structure measuring and manufacturing equipment, the parallel coordinate measuring machine has been paid more attention and developed rapidly. The parallel coordinate measuring machine is considered as a multi-body system, joints are important components to connect an individual body together [2]. The joint clearances can have a significant effect on dynamic response of the high-speed parallel mechanism system. For instance, the impact due to clearance might give rise to noise and vibration, and result in a loss of precision.

S. Dubowsky [3] published the first literature about dynamic behaviors of mechanism with clearances. Thereafter, several researchers [4-6], such as P. Flores, M. Dupac, and R. Haines, carried out related research individually. Currently, the study of dynamic modeling and dynamic characteristics on planar parallel mechanism are mature, but there have been few efforts made oriented to spatial parallel mechanism, especially on parallel coordinate measuring machine. When considering the joints effects, the dynamic equation of parallel coordinate measuring machine educed by theoretical method are extraordinarily complex, and the mathematical solution process is also difficult, which it is inconvenient for the follow-up research, such as the optimization design and the vibration control. Therefore, the dynamic behaviors analysis of parallel coordinate measuring machine with clearances without the construction of mathematical model is the key research tendency, and has not been studied extensively.

In this paper the dynamic behavior analysis of 4-UPS-RPS parallel coordinate measuring machine with clearances by using virtual prototyping technology is studied. The virtual prototype of 4-UPS-RPS parallel coordinate measuring machine with clearances is constructed in Adams while the driving limbs, the moving platform and stationary platform were treated as rigid bodies. Based on the dynamic model above, the simulation analysis of dynamic characteristics for 4-UPS-RPS parallel coordinate measuring machine with clearances, including displacement output response, velocity output response, acceleration output response, and contact force of joints element, are realized.

2. Structural Characteristics of 4-UPS-RPS Parallel Coordinate Measuring Machine

The 4-UPS-RPS parallel coordinate measuring machine is shown in Fig. 1, which could achieve two translation degrees of freedom and three rotation degrees of freedom.

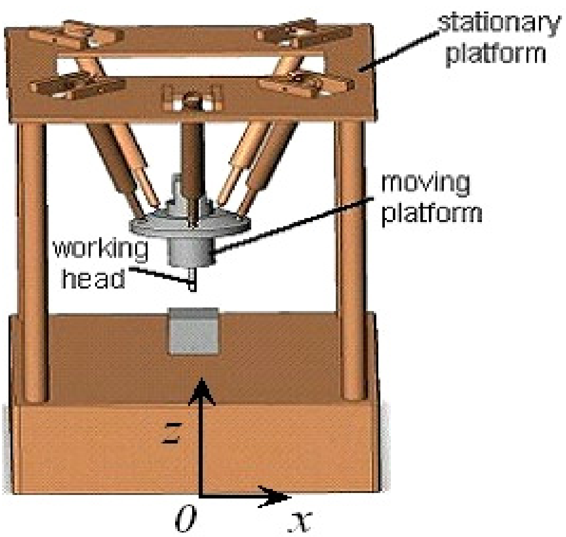

Fig. 1. Structural diagram of parallel coordinate measuring machine.

In the 4-UPS-RPS parallel coordinate measuring machine, the moving platform and the stationary platform are connected by four UPS actuating limbs and a RPS actuating limb. The five axes of the actuating limbs do not intersect at a common point. The distribution position angle of the universal joint on the stationary platform is 90°, the distribution position angle between the front revolution joint and the neighboring universal joint on the stationary platform is 45°, the distribution position angle of the spherical joint on the moving platform is 72°. Each limbs and platforms is made of steel with mass density of 7800 Kg/m^3, poisson's ratio of 0.29, stiffness of 10^5 Newton/mm, young's modulus of 2.07×10^5 Newton/mm*2, damping of 10.0 Newton-sec/mm.

3. Dynamic Characteristics of 4-UPS-RPS Parallel Coordinate Measuring Machine with Clearances

We take the driving limbs, moving platform and the stationary platform as rigid bodies, and the joint contact action is assumed as an isotropic contact stiffness/damping set. The process of constructing the virtual prototype of 4-UPS-RPS parallel coordinate measuring machine with clearances is illustrated as follows. Firstly, parts of 4-UPS-RPS parallel coordinate measuring machine are sculpted with measurement equal to its real model, respectively. And according to the actual assembly process, the solid model of 4-UPS-RPS parallel coordinate measuring machine is built in Solidworks. Then the solid model of 4-UPS-RPS parallel coordinate measuring machine is transmitted to ADAMS, using the rigid constraints of joints element, the virtual prototype of 4-UPS-RPS parallel coordinate measuring machine with different clearances was build. The motion of working head for 4-UPS-RPS parallel coordinate measuring machine is described as follows.

$$\begin{cases} x = 7.0710678119 & (0\le t\le 3.1416) \\ y = 926.5 + 50 * \sin t \\ z = 757 + 50 * \cos t \end{cases} \tag{1}$$

The dynamic characteristics simulations of 4-UPS-RPS parallel coordinate measuring machine with clearances are realized in ADAMS software. The clearance of revolution joints is defined as 0.6 mm, the clearance of prismatic pair is defined as 0.2 mm, the clearance of spherical joint is defined as 0.3 mm. Based on the virtual prototype of 4-UPS-RPS parallel coordinate measuring machine with clearances, the kinematics output response and contact force of joints element are realized. The kinematics output of working head are shown in Fig. 2 to Fig. 4. As shown in Fig. 2 to Fig. 4. The curves with red real line reflects the kinematics output of the dynamic model with ideal joints, the curves with dotted line reflects the kinematics output of the dynamic model with multiple clearance joints. From Fig. 2 to Fig. 4, the joint clearances have a strong impact on the kinematics output of 4-UPS-RPS parallel coordinate measuring machine.

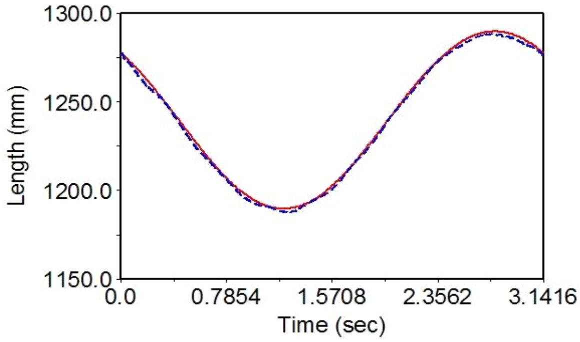

Fig. 2. Displacement output of working head.

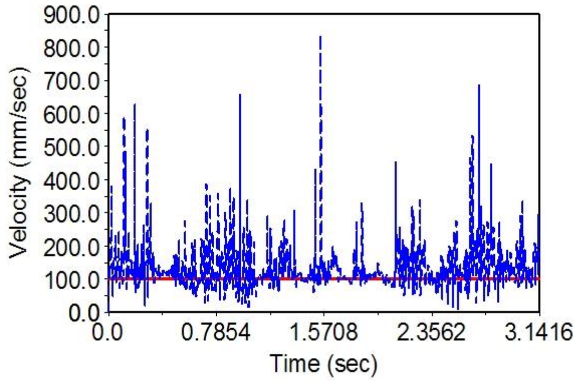

Fig. 3. Velocity output of working head.

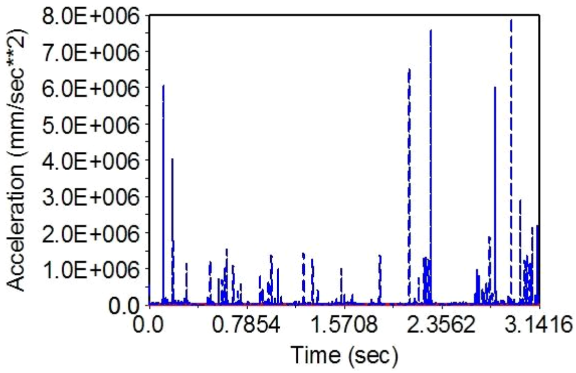

Fig. 4. Acceleration output of working head.

The contact force of joints element of 4-UPS-RPS parallel coordinate measuring machine with clearances is shown in Fig. 5 to Fig. 23. As shown in Fig. 1, the UPS limb in right rear is considered as the first driving limb. And the second limb, the third limb, the fourth limb and the fifth limb are installed in anti-clockwise respectively. The universal joint is considered as two revolution joints. The RPS driving limb has three joints, and the first joint is revolution joint connect with stationary platform, the prismatic pair is the second joint, the spherical joint is third joint. The UPS driving limb has four joints, and the first joint is revolution joint connect with stationary platform, the other revolution joint is second joint, the prismatic pair is the third joint, the spherical joint is fourth joint. The j joint on i driving limb is expressed as $i-j$ joint $(i=1,2,3,4,5;$ $j=1,2,3,4,5)$. From Fig. 5 to Fig. 23, the contact forces are varied greatly with the movement of the working head, and the supreme contact force occurs in spherical joint on RPS driving limb.

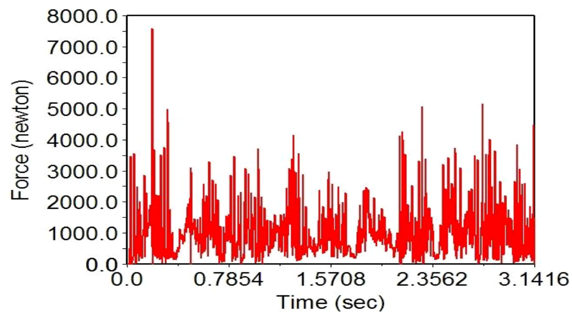

Fig. 5. Contact force in 1-1 joint.

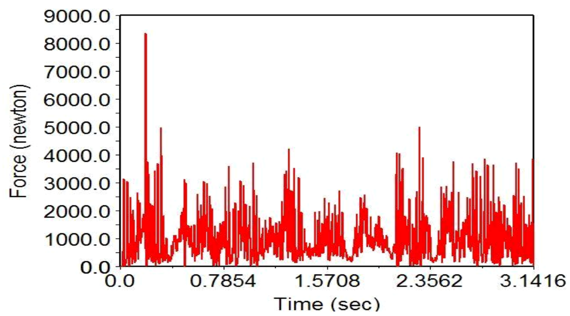

Fig. 6. Contact force in 1-2 joint.

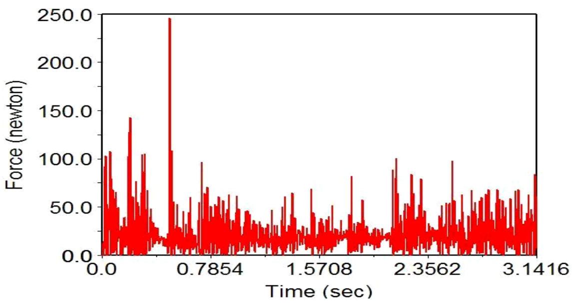

Fig. 7. Contact force in 1-3 joint.

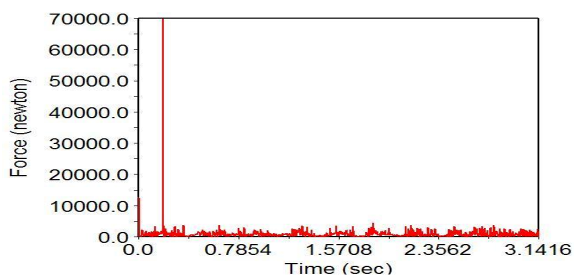

Fig. 8. Contact force in 1-4 joint.

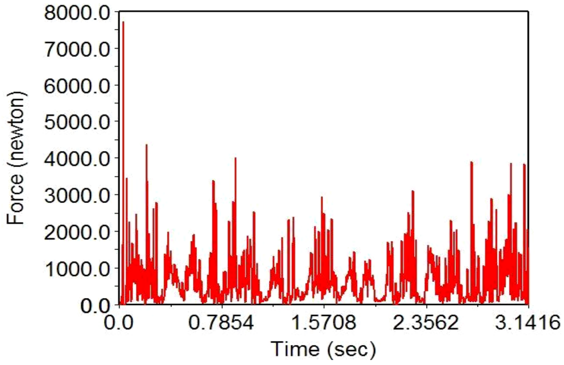

Fig. 9. Contact force in 2-1 joint.

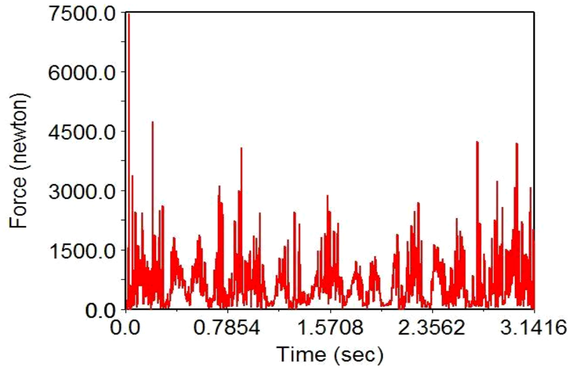

Fig. 10. Contact force in 2-2 joint.

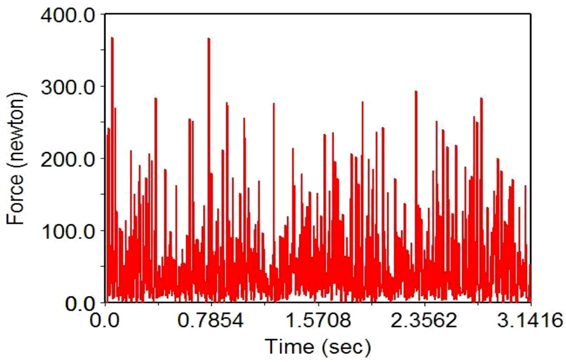

Fig. 11. Contact force in 2-3 joint.

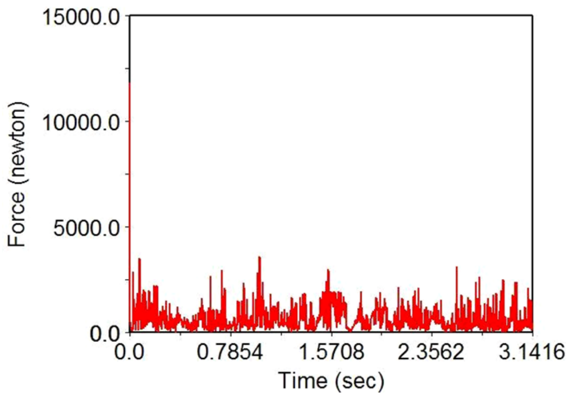

Fig.12. Contact force in 2-4 joint.

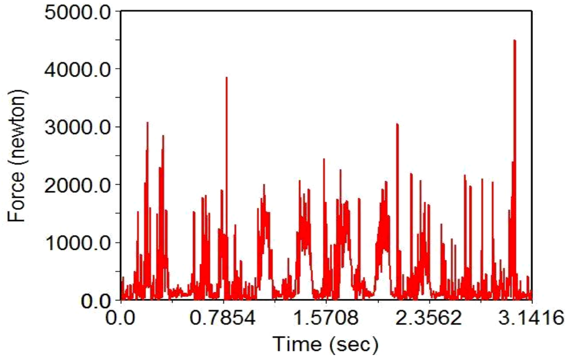

Fig. 13. Contact force in 3-1 joint.

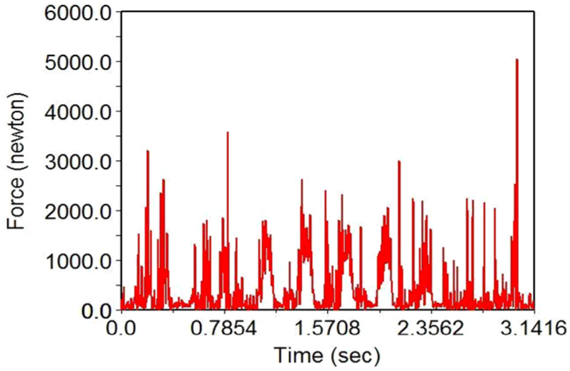

Fig. 14. Contact force in 3-2 joint.

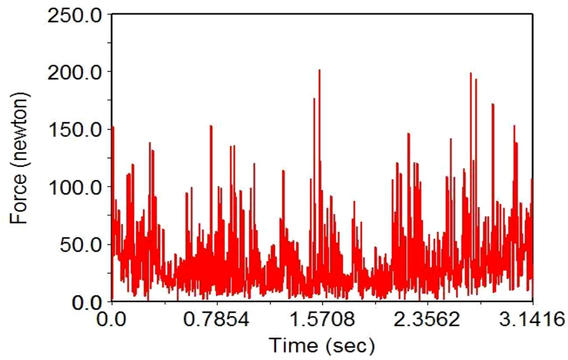

Fig. 15. Contact force in 3-3 joint.

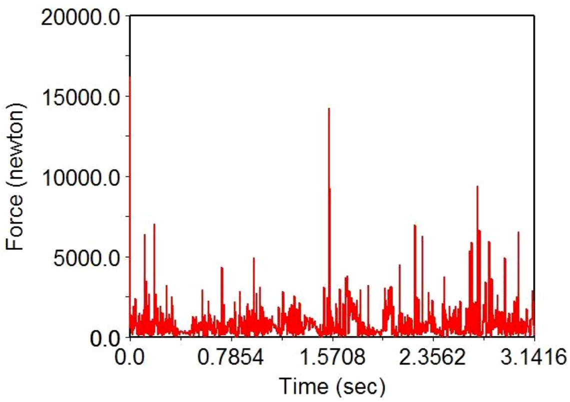

Fig. 16. Contact force in 3-4 joint.

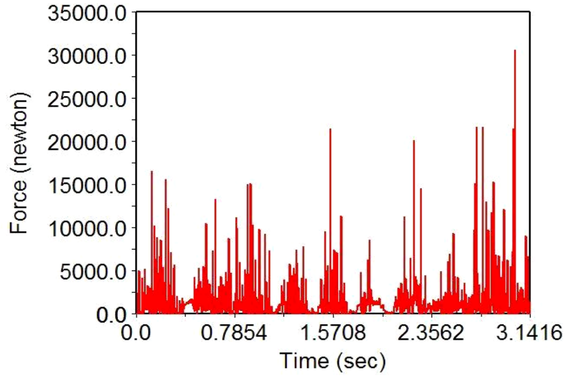

Fig. 17. Contact force in 4-1 joint.

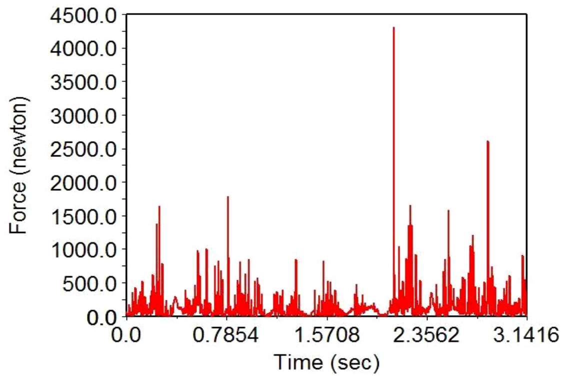

Fig. 18. Contact force in 4-2 joint.

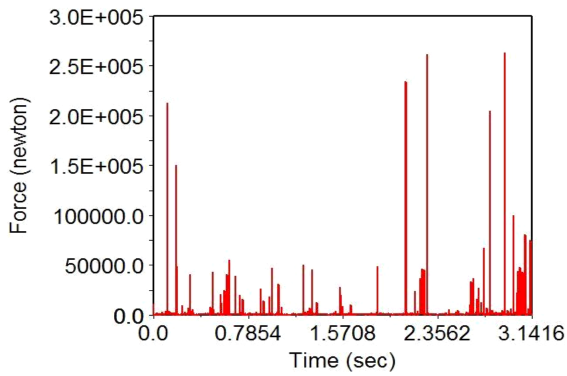

Fig. 19. Contact force in 4-3 joint.

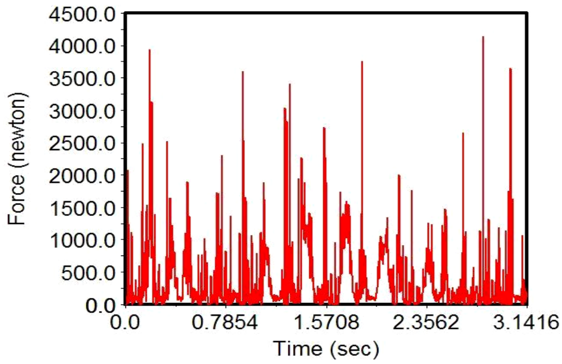

Fig. 20. Contact force in 5-1 joint.

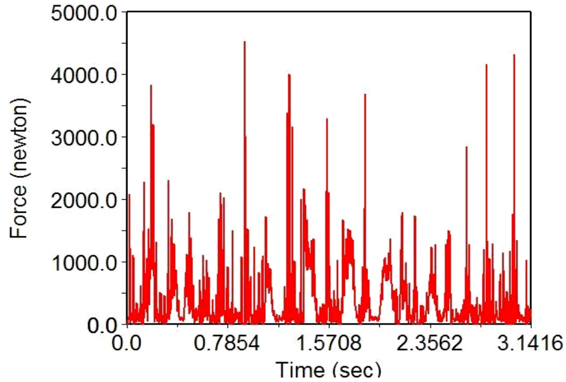

Fig. 21. Contact force in 5-2 joint.

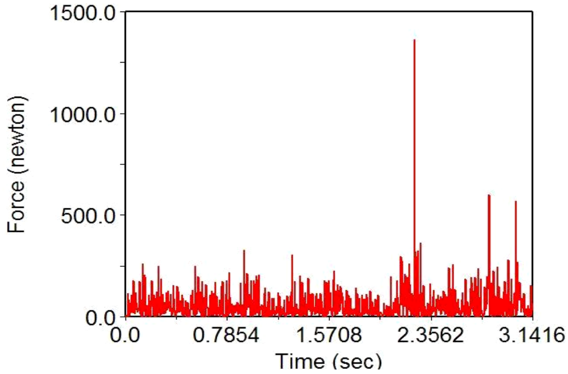

Fig. 22. Contact force in 5-3 joint.

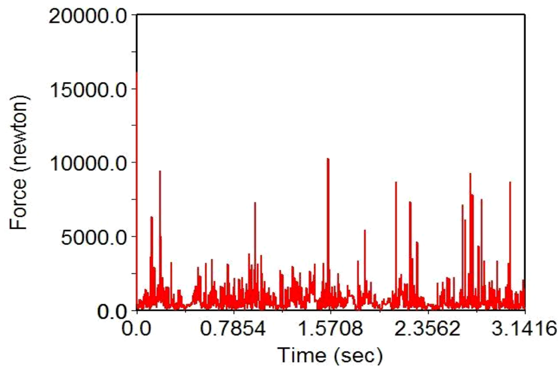

Fig. 23. Contact force in 5-4 joint.

4. Conclusions

The dynamic behavior analysis of 4-UPS-RPS parallel coordinate measuring machine with clearances are realized by the application of virtual prototyping technology. The dynamic characteristics including displacement output, velocity output, acceleration output, and contact force of joints element, are obtained. The simulation results show the actual dynamic behaviors of 4-UPS-RPS parallel coordinate measuring machine with clearances, and provide important theoretical base of the optimization design, controlling and reducing vibration for these parallel mechanism.

Acknowledgements

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