

The Dynamics of the System for the Constant Force Polishing on the Multi-robot

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Received: 22 May 2014 / Accepted: 29 August 2014 / Published: 30 September 2014

Abstract: In this paper, the research of the dynamics for the constant force polishing robot system as the goal, through the establishment of the dynamics equations for the end of the robot polishing, a modal analysis of the end of the robot is analyzed. It is obtained its static characteristic and vibration characteristics by the analysis results and verified the meeting requirements of the stiffness and the strength. By comparing the before and the after installation of terminal buffer actuator force was verified by the experiment, the feasibility and stability constant of the system for the constant force polishing on the multi-robot are obtained. Copyright © 2014 IFSA Publishing, S. L.

Keywords: Constant force polishing, Multi-robot, Modal analysis.

1. Introduction

In the past, the physical contact in the application for the system of the polishing tool (i.e., industrial robot) is rarely involved, when the robot moving in the free space, there would be no force. The good effect can be achieved depending on the position sensor monitoring the tasks, collecting the sensor data, fixing the motion commands. Nowadays, along with the expansion of application fields of the polishing tool system, physical contact is more and more possibility and the problem will be more prominent [1-3].

Related studies have shown that the quality of spherical polishing is determined by the polishing pressure between the polishing tools and the aspheric surface and the pressure will be real-time changed along with curvature radius of the aspheric surface, the polishing force on the aspheric surface and the posture of the polishing tool [4, 5]. If the polishing pressure is too large, the aspheric surface will be over

lapped and even the polishing tools will be damaged; if the polishing pressure is too small, the aspheric surface of the material removal rate is reduced and polishing efficiency is lower. In order to improve the quality of polishing and maintain the polishing pressure constant, the force of polishing need to be controlled in time [6, 7]. Therefore, based on the dynamics equations and the mechanics model which is already established of the polishing robot, the effect on the each joint of the robot can be analyzed by Adams under the condition that the polishing force is changed on the polishing end.

2. The Composition of Polishing MAS

The polishing system is made up of the Motoman series robot, the system of elastic polishing tool, the NPT800 parallel moving platform and the man-machine interface that responsible for the whole situation. Its structure is shown in Fig. 1. In addition

to the movement controller and the series robot and parallel moving platform, the function of the interaction, reasoning and collaboration is realized by a local PC. Network communication system is the C/S structure. In it, series robot and parallel moving platform are regarded Client and the PC which is responsible for whole task in the system is regarded as the Server. Different work and task are finished by different parts. It is depended on the coordination and cooperation each other in order to finish the polishing of surface eventually.

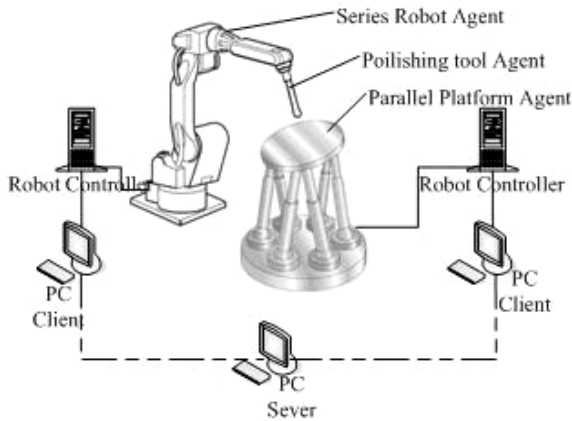


Fig. 1. MAS model of polishing system.

3. The Stiffness Analysis of Robot End

The terminal of the polishing robot arm which contacts with the free surface will be sustained force from the surface and then a shift change will be resulted, as shown in Fig. 2. This shift affects the positioning accuracy of robot arm to a certain extent. So, how to effectively control the deformation becomes the key technology of robot polishing.

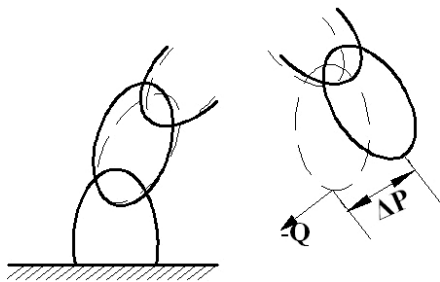


Fig. 2. The shift of sustained force of the terminal of the polishing robot arm.

The size of the terminal displacement is decided by the capacity of robot arm's stiffness and load. The stiffness varies as the robot terminal position. If the terminal stiffness is controllable, it can be controlled terminal execution under a certain terminal displacement. So control the stiffness and position of the terminal at the same time, it can be controlled the

force of the terminal in the range of the allowed deflection, so as to realize the constant force of the robot polishing.

Through the above analysis, the main factors that influence the robot terminal stiffness is driven stiffness and transmission stiffness. Only to ensure the transmission stiffness of the robot, the good effect of the robot terminal can be ensured.

The stiffness of any joint i of the MOTOMAN-HP3 robot in the transmission for industrial scale is k_i ($i = 1, 2, \dots, 6$), the driving torque of joints m_{ii} is as follows:

$$m_{ii} = k_i \Delta a_i \quad i = (1, 2, \dots, 6) \quad (1)$$

Namely

$$M_6 = K \Delta a \quad (2)$$

In the Eq. (2): $M_6 = [m_{11} \ m_{22} \ \dots \ m_{66}]^T$ is the vector of driving torque. $\Delta a = [\Delta a_1 \ \Delta a_2 \ \dots \ \Delta a_6]^T$ is the vector of deflection rotation.

$$K = \begin{bmatrix} k_1 & 0 & 0 & 0 & 0 & 0 \\ 0 & k_2 & 0 & 0 & 0 & 0 \\ 0 & 0 & k_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & k_4 & 0 & 0 \\ 0 & 0 & 0 & 0 & k_5 & 0 \\ 0 & 0 & 0 & 0 & 0 & k_6 \end{bmatrix} \quad (3)$$

$$M_6 = J^T Q$$

It is described by Jacobi matrix

$$\Delta P = J \Delta a, \quad (4)$$

where ΔP is the variable displacement of the terminal position (Fig. 2)

From Eq. (2):

$$\Delta a = K^{-1} M_6 \quad (5)$$

Requirements for k_i ($i = 1, 2, \dots, 6$) are not zero to K^{-1} .

Eq. (5) is substituted by Eq. (3) to get:

$$\Delta a = K^{-1} J^T Q \quad (6)$$

Eq. (5) is substituted by Eq. (4) to get:

$$\Delta P = J K^{-1} J^T Q \quad (7)$$

for

$$C = JK^{-1}J^T, \quad (8)$$

where C is the flexibility matrix of the robot, when C^{-1} was present when:

$$\Delta P = CQ \quad (9)$$

So

$$Q = C^{-1}\Delta P \quad (10)$$

where C^{-1} is the stiffness matrix of robot. C is related with the position and pose of the robot. The size and direction of ΔP depends on the robot's pose and Q .

4. Modal Analysis of Tools System

4.1. Stress Analysis of Tools System

In Fig. 3, the material of the upper flange plate, the threaded connection and the Polishing tool clamping piece are set for aluminum alloy. The material of the polishing tool clamping piece is steel 45#. Through analyzed the terminal execution tool system, the distribution of the stress and strain is checked.

In Fig. 4, it is the overall situation and the member's situation by force.

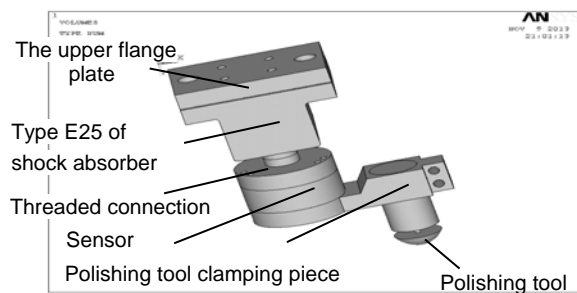


Fig. 3. Model of terminal buffer actuator.

When it is deformed, the maximum stress is in the polishing head shaft. But the polishing head connecting shafts are made of alloy steel; it can withstand the pressure in the polishing process. In addition, the deformation is larger in the polishing tool clamping piece and a threaded connection. It can be seen from the Fig. 4 that is completely in the allowable force range. From the above static analysis results, the design of the terminal buffer actuator is in full compliances with the requirements of stiffness and strength for the constant force polishing control system.

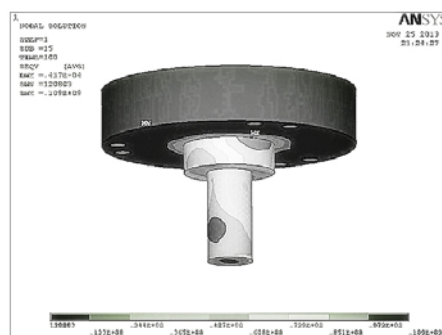
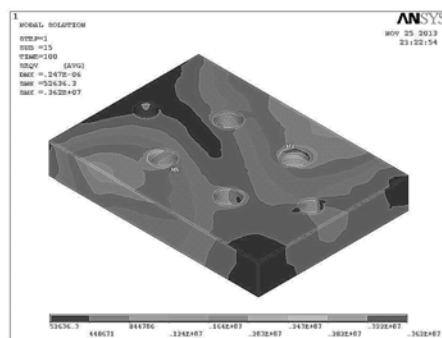
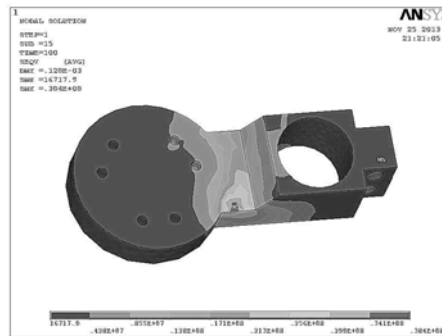
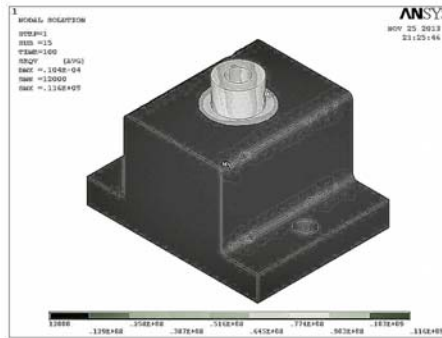
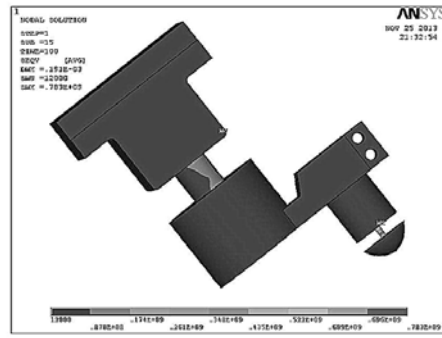


Fig. 4. The member's situation by force.

4.2. Modal Analysis of Constant Force Polishing Tool System

In this paper, it is analyzed the modal of three-dimensional simplified model on the terminal execution tool system by software ANSYS. Through the modal analysis, the first three vibration modes are analyzed. Table 1 is three orders frequency. Fig. 5(a), Fig. 5(b), Fig. 5(c) is the three orders of vibration and deformation.

Table 1. The three orders of vibration frequency.

Mode	Vibration (Hz)
1	705.823
2	740.314
3	1509.56

The analysis reveals that the deformation is the most obvious in the connecting shaft of the polishing head on the terminal buffer implementation and the connecting parts in the shock absorber. Then how to choose the right polishing head is very important. It can avoid the damage of the deformation in the absorber end by increasing the washer or selecting suitable materials. In addition, it is more prone to vibration when the robot starts and its movement is instability. It is need to wait a few seconds for the surface processing after into its steady state. That can avoid the resonance destruction.

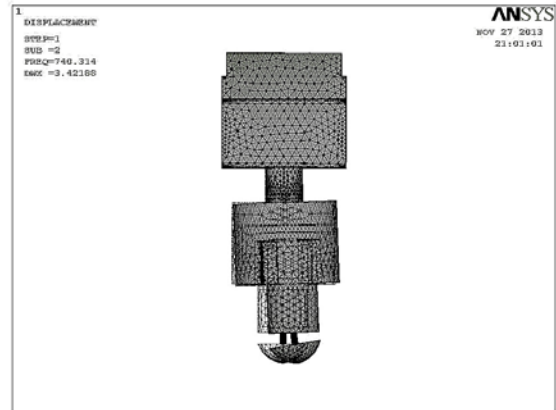
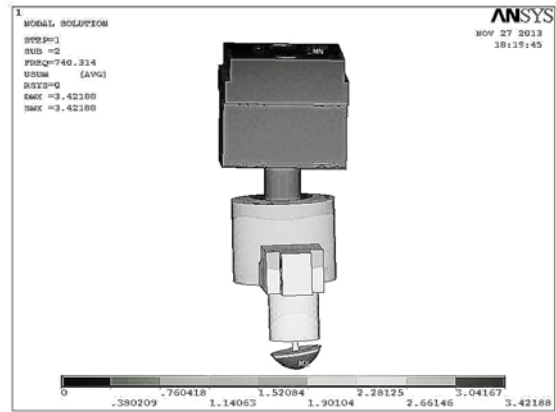


Fig. 5 (b). The second order vibration and deformation

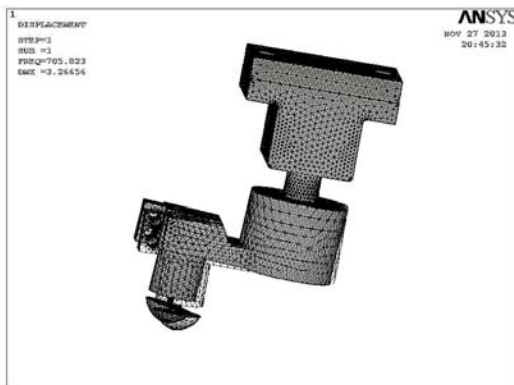
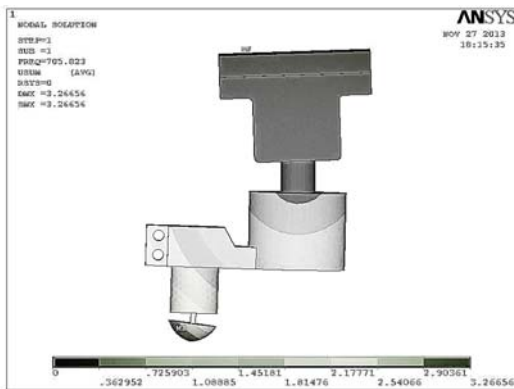


Fig. 5 (a). The first order vibration and deformation

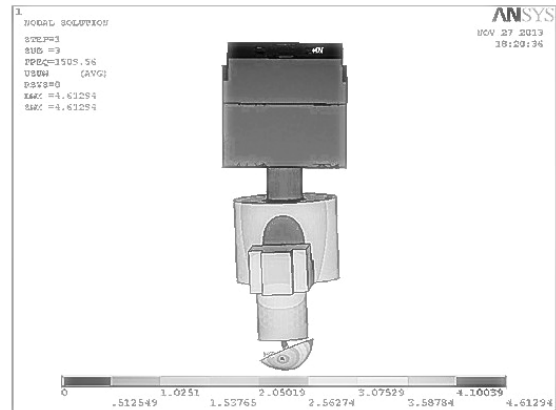


Fig. 5 (c). The third order vibration and deformation

5. The Experiments of the Polishing Pressure

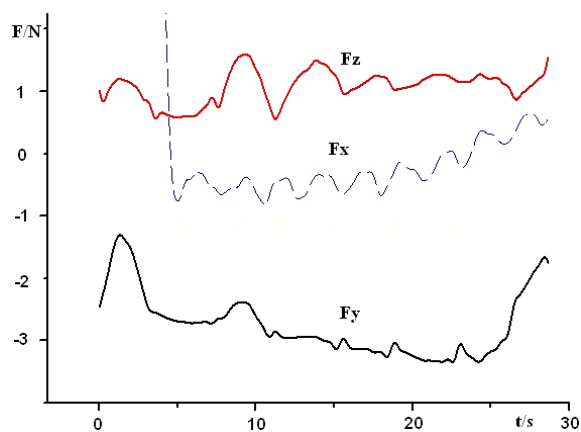
In order to be able to prove that the constant polishing control system can get good processing quality and processing efficiency in the practical machining, this paper uses the way of comparison before and after processing. The first is the comparison of the polishing pressure and torque, and then is the comparison of the compared before and after polishing quality.

Through the arc coordinated motion of the multi-robot, it is measured the changes of the force and moment before and after the installation of terminal buffer actuator.

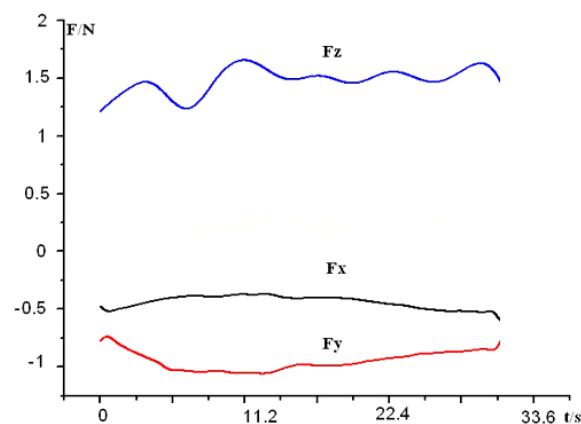
It is shown in Fig. 6 and Fig. 7. It can be seen that the constant the polishing processing can be ensured by the terminal buffer actuator.

Meanwhile, it can be seen that the torque T_x and the other force has slightly changed.

This is because the interpolation operations in arc, which needs to select three points to determine a circle. So it needs to transmit signals again in the middle of computer. It can basically realize the stable machining.

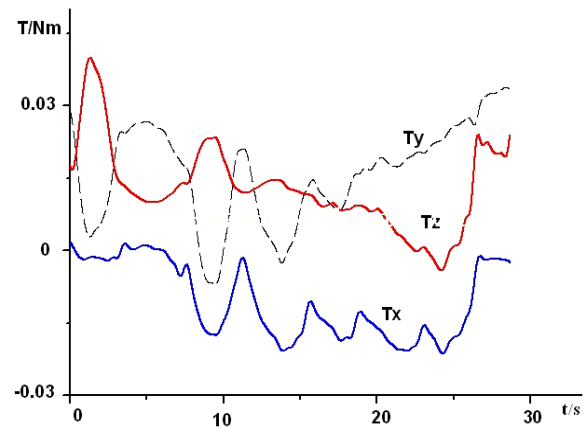


(a) The before installation of the terminal buffer actuator

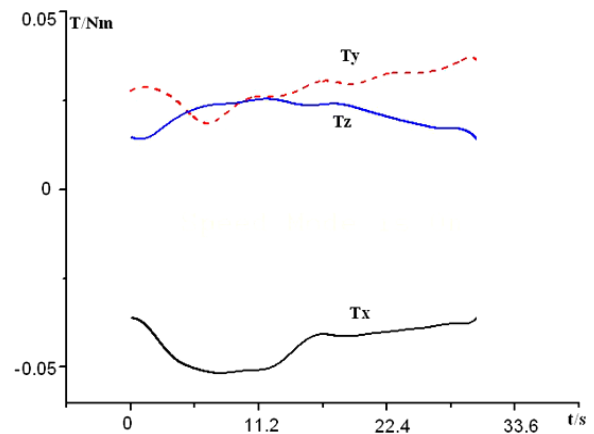


(b) The before installation of the terminal buffer actuator

Fig. 6. Change of arc in polishing process of force.



(a) The before installation of the terminal buffer actuator



(b) The before installation of the terminal buffer actuator

Fig. 7. Change of arc in polishing process of torque.

6. Conclusions

Through the analysis of the simulation for the serial robot, the design scheme of the terminal buffer device is proposed and the appropriate buffer components are selected. The analysis results of its static characteristic and vibration characteristics of the structure are obtained by the finite element analysis of the tool system. The requirements of strength and rigidity are satisfied.

In this paper, it is polished on the work piece surface by the arc interpolation methods with the multi-robot coordination. By contrasting the force of the before and after the installation of terminal buffer actuator, the feasibility and stability are verified on the multi-robot of the polishing control system.

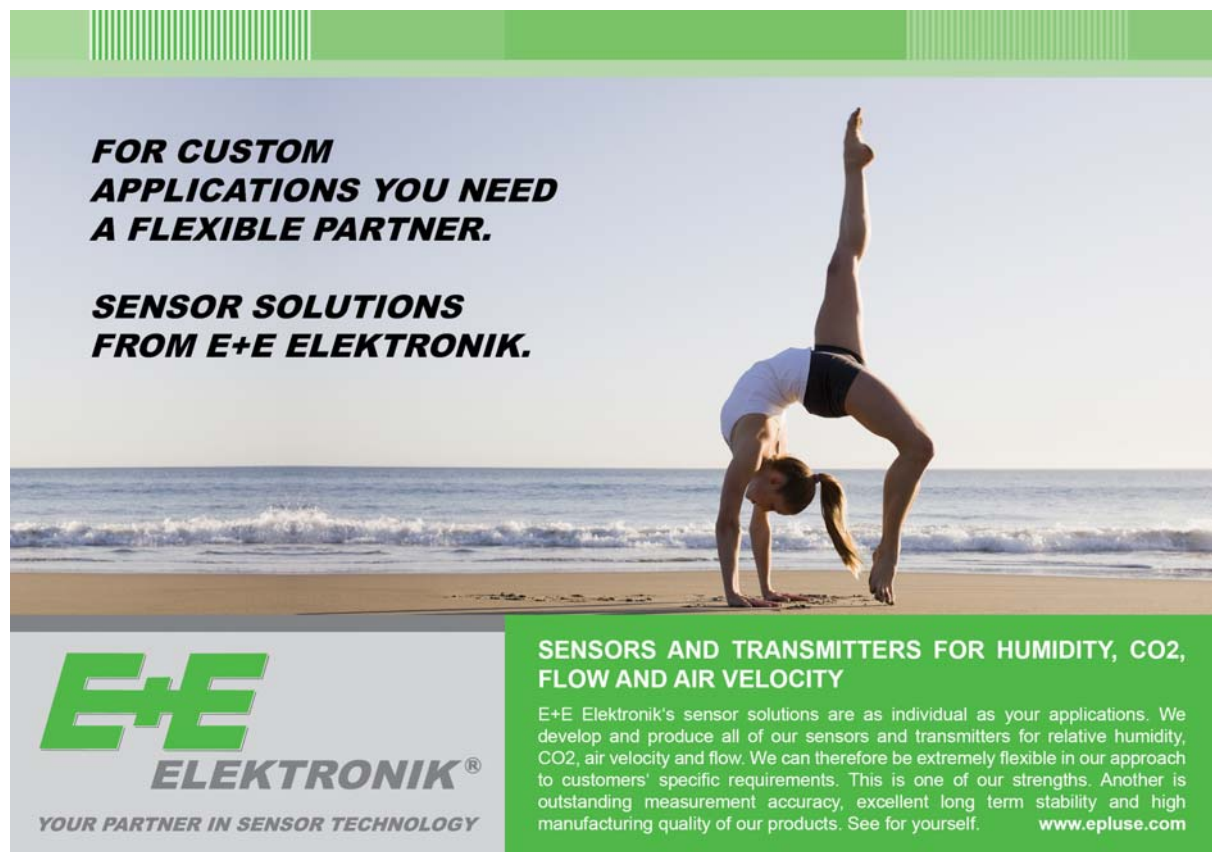
Acknowledgements

This research is sponsored by the fund of Jilin Science Commission (201215114) and the fund of the Development and Reform Commission (2013C038-2).

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