

論文 / 著書情報  
Article / Book Information

題目(和文)	球対偶を有するパラレルロボットの対偶すきまを考慮した動力学解析と駆動トルク測定に基づく対偶すきまの同定
Title(English)	Dynamic analysis of parallel robot with spherical joints considering joint clearances and clearance identification based on actuation torque measurement
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Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

## 論文要旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	機械 機械	系 コース	申請学位 (専攻分野)： Academic Degree Requested	博士 Doctor of	(工学)
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要旨 (英文 800 語程度)

Thesis Summary (approx.800 English Words )

Since the joint clearance caused by wear during the continuous operation of the robot leads to output error and vibrational behavior of the robot, it is required to evaluate the effect of the joint clearance to prevent the accidents. This thesis targets a parallel DELTA robot and proposes methods to perform kinematics and dynamics of the parallel robot having many spherical joints with consideration to joint clearance to investigate the output error and vibrational behavior and to identify joint clearance based on the measurement of actuation torque fluctuation caused by the impact at the clearance joint.

Firstly, considering the case where the vibrational behavior caused by joint clearance is negligible, error analysis method by kinetostatic model of clearance joint is proposed. Since the output error is modeled by the joint reaction force calculated under the condition that all joints are ideal, the method does not need numerical integration. This method was validated by an experiment to measure the acceleration of the output link and to get the position error. A time to attenuate the vibrational behavior, when the joint reaction force changes is focused on as an index to evaluate the accuracy of the proposed method. An approximation method of the index analyzing bounding and sliding motions of joint elements with simple model is proposed. The validity of the approximation method is confirmed by comparing the calculated index with the value obtained by experiment.

Secondly, a method of dynamics to analyze the vibrational behavior of the parallel robot having many spherical joints caused by joint clearance is proposed. By using variables that represent the relative position vectors between joint elements as generalized coordinates, it is enabled to implement a general algorithm regardless of the combination of spherical joints whose clearances are considered. The method does not need to use Baumgarte constraint stabilization method. The acceleration of output link was experimentally measured with the use of target trajectories which are likely to cause the impact only at single spherical joint at the beginning of motion, and was compared with the simulation results to validate the analysis method. From the results of simulation, several motion modes of joint elements due to the clearance are confirmed: free flight, impact, and continuous contact modes. The acceleration of the output link fluctuates significantly at the time when the joint elements are in the impact mode, which shows the impact of joint elements at the spherical joints with clearance causes vibrational behavior of the robot. The appearance of the acceleration fluctuations are coincided with that of experimental results. This shows the effectiveness of the proposed method as a method for analyzing the vibrational behavior caused by joint clearance.

Thirdly, to measure how much the impact in clearance joint affects the actuation torque waveform, "Joint Impact Index" is introduced as an index to quantitatively evaluate the vibrational behavior caused by the impact of joint elements at a spherical joint with clearance. This index focuses on the behavior of joints at the time of separation of joint elements, and approximates the work done by a "force" virtually defined for the relative motion of joint elements. In order to identify the clearances at many spherical joints based on actuation torque measurement, an order reduction method for the identification problem by trajectory design is proposed. If the robot operates using a certain trajectory (called "target trajectory") which causes the impact of joint elements only in one joint (called "target joint"), the existence of clearance in that joint can be detected by the measurement of actuation torque fluctuation. For the design of the target trajectory, objective functions were defined based on the Joint Impact Index, and multi-objective optimization problem is formulated. This method was applied to the analysis model of the DELTA robot, and was investigated by the experiment to measure the actuation

torque with the real machine. From the results of the experiment, the actuation torque fluctuates significantly due to the excessive clearance in the target joint for the target trajectories designed to cause the impact at the spherical joints located on the output link. This shows the order reduction was successfully done by the proposed trajectory design method. With the use of machine learning model, detection performance of excessive clearance was investigated. As the results, the effectiveness of designed target trajectories for the detection of excessive clearance in the spherical joint is shown.

Finally, by using the results of the dynamic analysis, a method for identifying the joint clearance of a parallel robot not only by target trajectory but also under the general trajectory condition is proposed. By constructing a mathematical model which associates the joint clearance with the torque fluctuation caused by the impact at the clearance joint with respect to the results of the dynamic analysis and those of the measurement by the real machine, and then, by solving the model, the clearance sizes of spherical joints are identified. This method was applied to the DELTA robot, and the detection performance of joint clearance was investigated by using the results of experiment and simulation. It is confirmed that when the number of spherical joints which have excessive clearances is at most two, the excessive clearance of each spherical joint can be detected.

備考：論文要旨は、和文2000字と英文300語を1部ずつ提出するか、もしくは英文800語を1部提出してください。

Note: Thesis Summary should be submitted in either a copy of 2000 Japanese Characters and 300 Words (English) or 1 copy of 800 Words (English).

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