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Industrial high speed parallel robot: Development of a Robot and Analysis tools

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***Abstract*—It is important to get down the unit cost of production to get the price competitiveness. That is why the markets for the high speed handling robots are increasing. In this research, a high speed parallel robot has been developed and an analysis tool has been developed, also. The developed robot system was designed to get light weight and high speed and low vibrational motion. The developed analysis tool was designed to help the design processes. In this paper, the research results on the developed high speed parallel robot and the developed analysis tool will be introduced.**

***Index Terms*— Parallel kinematic machine, Vibrational motion, Light weight, High speed Robot, Modal Analysis.**

I. INTRODUCTION

Articulated 6 DOF manipulator were usually used to implement the automated production line. The parallel robots are not mainly used to implement the mass production line. Recently, it is becoming important to ensure the competitiveness of production cost of products with improved productivity, thus the demand for robot manipulators for faster operations is rapidly increasing. For this reason, the needs for the development of high-speed parallel kinematic robots are rapidly increasing. For this reason, the market of the high speed parallel robot is increasing.

In this research, a high speed parallel robot has been developed. The developed robot system was designed to get light weight and high speed and low vibrational motion. In this paper, the research results on the developed high speed parallel robot and developed analysis tool to help the design processes will be introduced.

II. DESIGN OF ROBOT

It is important that high speed parallel kinematic machines have to have light weight because they experience very high level of acceleration and deceleration [1~3]. Developed high-speed parallel robot consists of 3DOF parallel mechanism and 3DOF serial wrist structure. The first 3 DOF is designed as a parallel kinematic machine of 3 DOF, so called, Tripod, in this research. Because, in the Tripod, the actuators of the robot can be located not on the moving parts of the robot but on the fixed parts of the robot, so that the weight of the actuator may not consume the power. The orientation of the robot systems is designed as a serial manipulator, especially wrist of 3 DOF. The kinematical structure is shown in Fig. 1. The entire robot has 6 degrees of freedom.

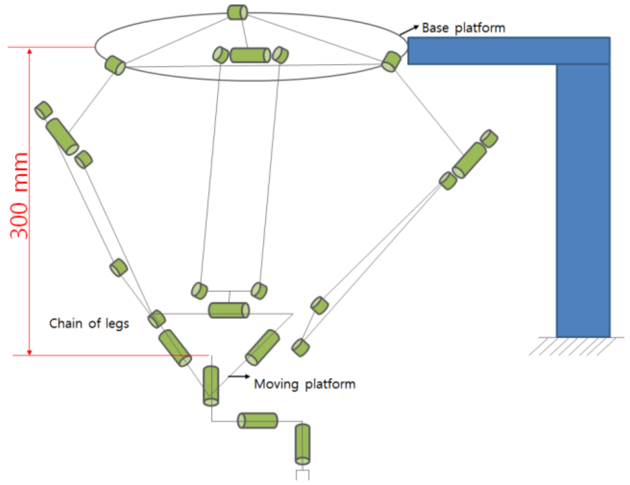

Fig. 1 Kinematic diagram of the parallel kinematic robot

Figure 2 shows the 3D CAD model of the developed parallel kinematic robots. The overall structure is composed of

- Base platform & support frame
- Turning gear & upper universal joint
- Hinge arm assembly
- Link arm assembly
- Lower universal joint
- Moving platform.

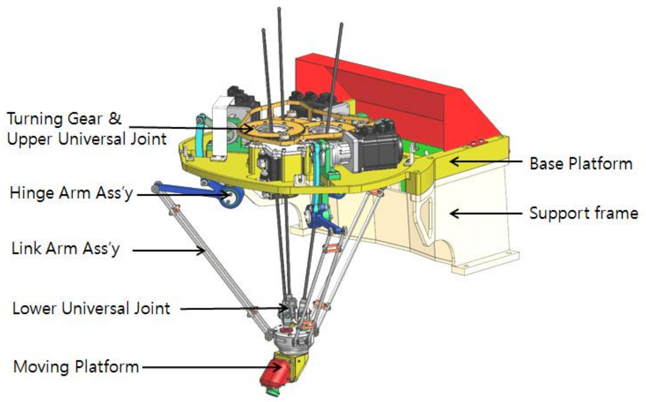

Fig. 2 3D CAD model of the developed parallel kinematic robot

Torque from the motor system is transferred to the link assembly by the hinge arm assembly shown in Figure 2. It consists of parallelogram shown in Figure 3. Figure 4 shows that the configurations of the parallelogram when the moving platform is at the workspace boundary. As shown in figure 4, the parallelogram goes to the singular configuration or near singular configuration when the moving platform moves to the workspace boundary. For this reason, the initial design

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angle of 28 degree is chosen considering the configuration of the parallelogram of the hinge arm assembly.

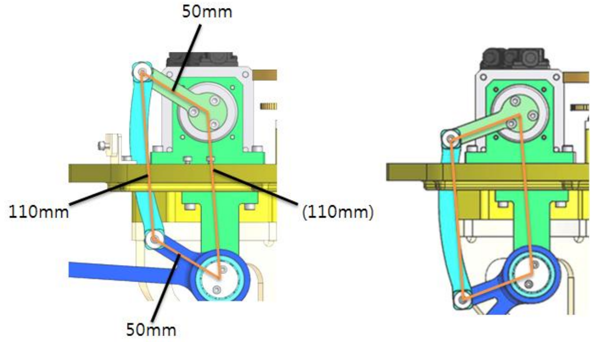

Fig. 3 Parallelogram of hinge arm assembly

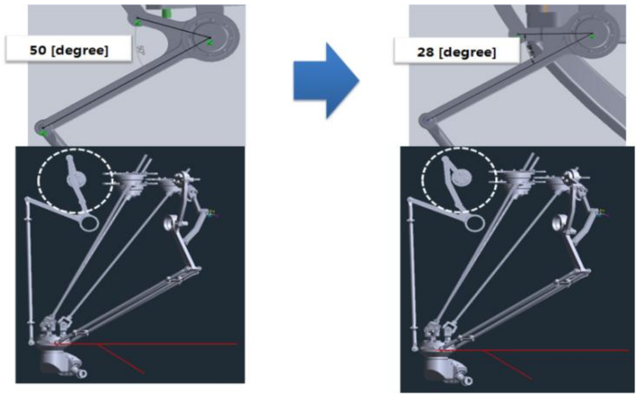

Fig. 4 The configuration of the parallelogram of the hinge arm assembly

A special universal joint mechanism (upper universal joint shown in Fig. 2) was developed to transfer the power of the actuator on the base platform to the wrist mechanism on the moving platform. That is composed of a power transfer axis, a linear ball spline, a universal joint, a turning gear housing and turning gear as shown in figure 5.

When the moving platform moves to the boundary of the workspace, the universal joint rotates and finally gets in contact with the rotational limits. In this reason, optimal design is very important for the upper universal joint. As a result, we have 44 degree of rotation of the universal joint limit at the workspace boundary.

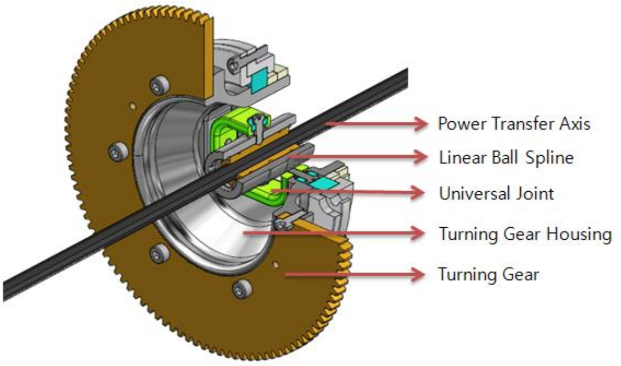

Fig. 5 The upper universal joint assembly for the power transmission from the actuator to the wrist mechanism on the moving platform

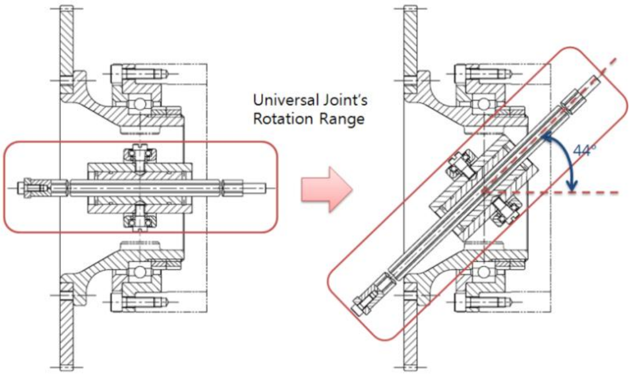

Fig. 6 The rotational limit of the universal joint for the power transmission from the actuator to the wrist mechanism on the moving platform

III. DESIGN OF ANALYSIS TOOLS

In Section 2, some important kinematic and mechanical design issues for a small size industrial high speed parallel robot were introduced. In this chapter, the other issue of the workspace analysis is introduced.

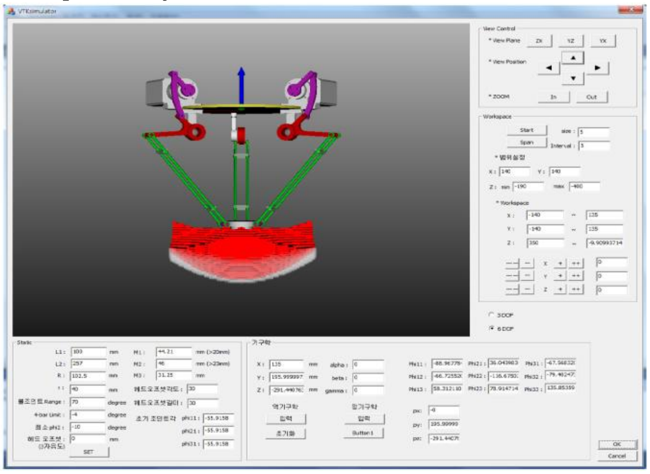

Fig. 7 Developed workspace analysis tool

We developed the simulation program for analyzing workspace. Figure 7 shows the developed workspace analysis tool. In the developed workspace analysis tool, the kinematic parameters can be changed to show their effect to the resultant working area. The user can put some kinematic information and joint rotational limits in the windows text control box to see their effects for the workspace of the robot system. Figure 8 shows the analyzed workspace using the developed workspace analysis tool. The final workspace was (65+105mm) in z direction and Dia. 360mm in XY plain.

In the design process, dynamic simulation tool was developed to compute the required motor torque and determine the required specifications of the mechanical parts to implement the robot hardware system. Figure 9 shows the screen capture of the dynamic simulation tool. The user can put some operational parameters, cycle time, travel distance, acceleration and deceleration, in the window text control box.

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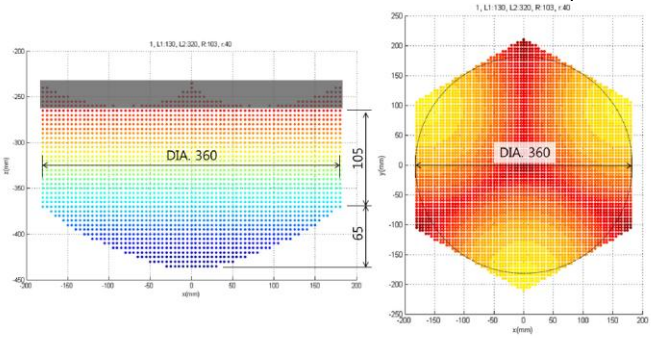

Fig. 8 Workspace analysis using the developed workspace analysis tool (Left: vertical workspace, Right: Horizontal workspace)

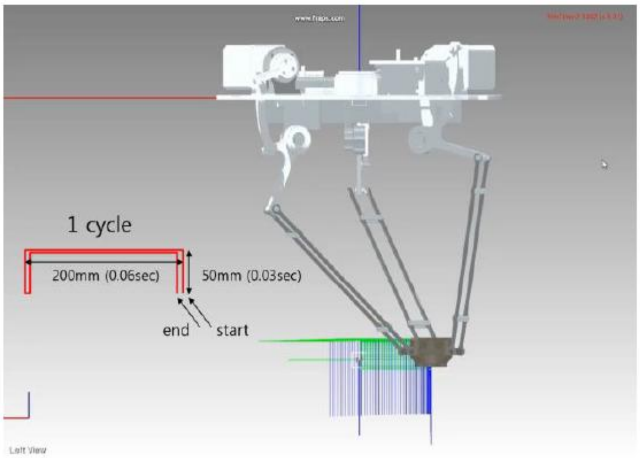

Fig. 9 The developed dynamic simulation tool

This dynamic simulation tool was developed using the Robotics LabTM which has dynamic simulation engine for multi-body dynamic system. In this system, the kinematic information was modeled using AML protocol. All 66 joints (90 degree of freedom) were modeled and 17 joints should be allocated to the jointed looping as shown in figure 11. Some additional constraints of 9 joints were added for the description of the gear mechanism.

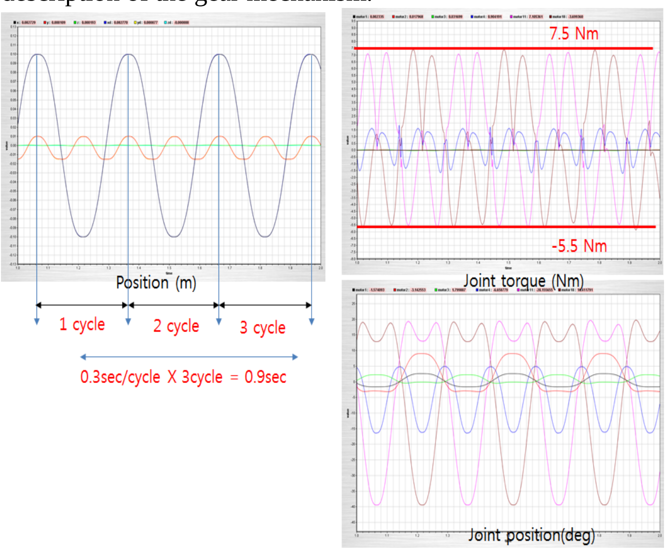

Fig. 10 The results of the dynamic simulation

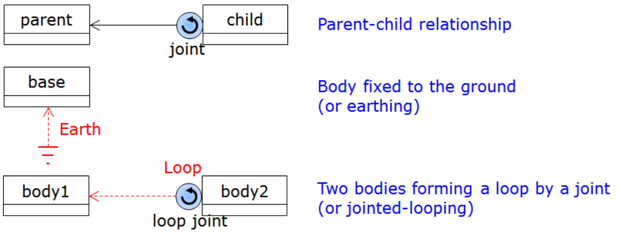

Fig. 11 Implementation of the looping and the constraint

IV. DYNAMIC ANALYSIS OF DEVELOPED ROBOT

After the kinematic design was finished, the conceptual 3D drawing was implemented. This 3D drawing has the information of the mass intensity and it is possible to analyze the dynamical vibrational motion. Figure 12 shows the FEM model [5] for the designed total robot system shown in Figure 2. Table 1 shows the result of modal analysis. For the developed robot system, the 1st mode is about 24Hz and the 2nd mode is about 25. For the 3rd mode, the natural frequency is radically changed from 25Hz to 49 Hz.

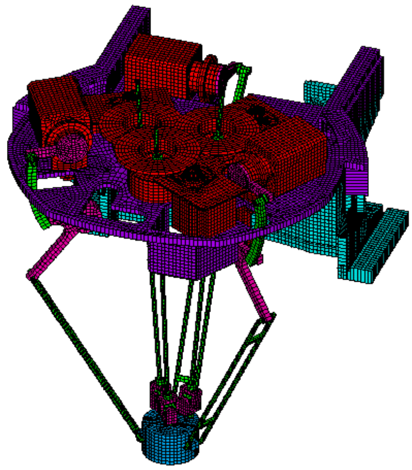

Fig. 12 FEM modeling of the parallel kinematic robot

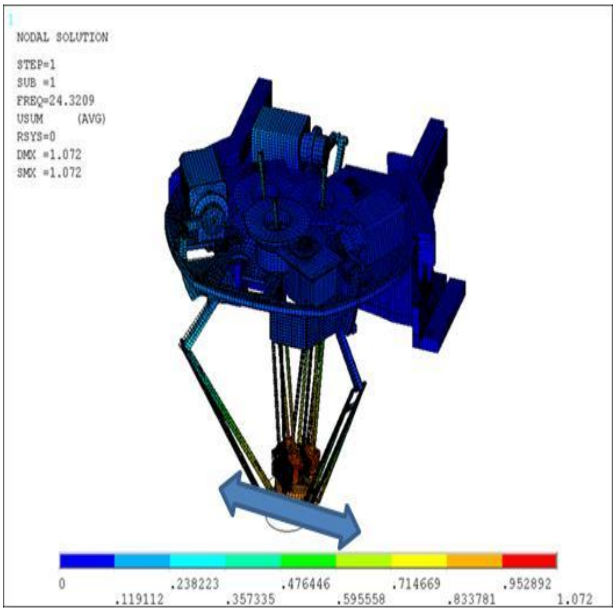

Fig. 13 Mode shape: 1^{st} mode (24Hz)

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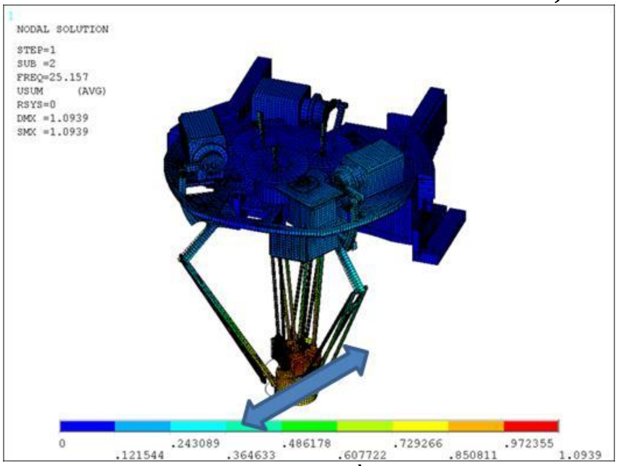

Fig. 14 Mode shape: 2nd mode (25Hz)

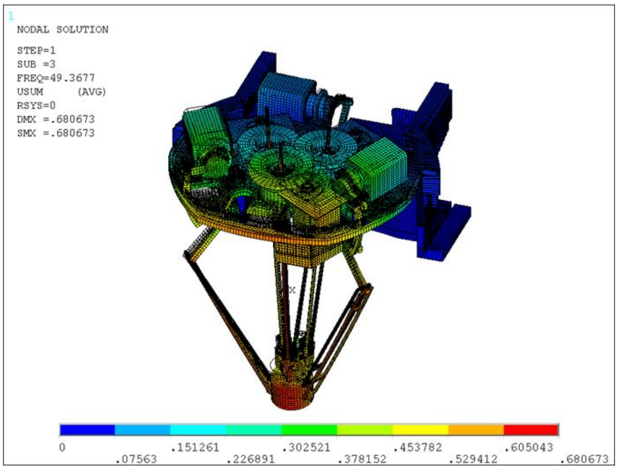

Fig. 15 Mode shape: 3rd mode (49Hz)

Figure 13 and 14 show the configuration of the 1st mode and the 2nd mode. Both of them has very similar modal motion, the 1st mode means the linear motion in X direction and the 2nd mode means the linear motion in Y direction. The 1st and the 2nd motion are the fundamental modes. The 3rd mode is shown in figure 15. The 3rd mode is very different from the 1st and 2nd motion because its motion is in Z direction, vertical mode. It shows that the z directional stiffness of the design robot is much higher than the x and y directional stiffness.

TABLE 1. THE RESULT OF MODAL ANALYSIS

Mode	Frequency
1st	24.3
2nd	25.2
3rd	49.4
4th	72.2
5th	72.3
6th	75.3
7th	76.0
8th	78.5
9th	79.2
10th	84.5

The developed parallel robot is used under 5G-acceleration or deceleration. Thus, dynamical vibrational motion is induced by the high speed inertial motion of the moving platform as shown in figure 16. For the analysis of dynamical vibrational motion, the maximum accelerating speed of 5G was supposed to be applied to the moving platform as in Fig. 17. Fig. 17 means that excitation by the inertial force occurs at the center of moving platform and P1, P2, and P3 mean the position of measuring the vibration.

Fig. 18 shows the vibrational motion frequency at P1, P2 and P3 position with harmonic excitation at the moving platform. The red line shows vertical vibration and the blue and black lines show horizontal vibration. The resonance frequency was about 24Hz and 50Hz and they coincide with the result of mode analysis. The 24Hz resonance frequency of left-right vibration and front-back vibration forms the primary mode and secondary mode, respectively, and this coincides with the results of modal analysis.

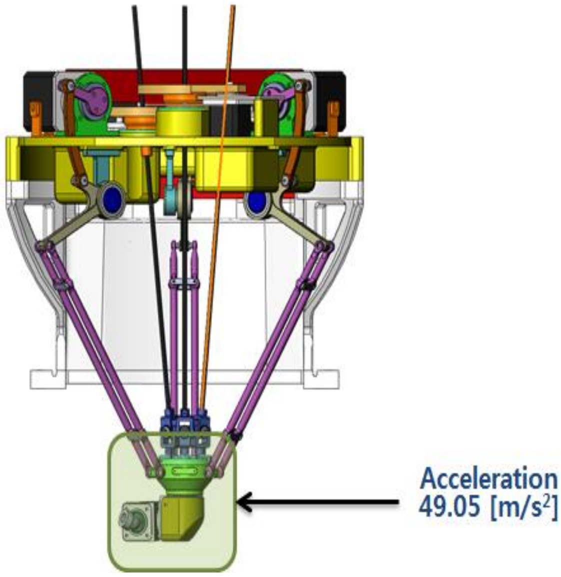

Fig. 16 The moving platform under the maximum acceleration

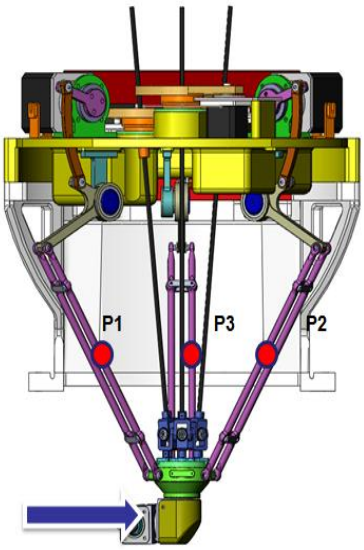

Fig. 17 Excitation location & vibration measurement position

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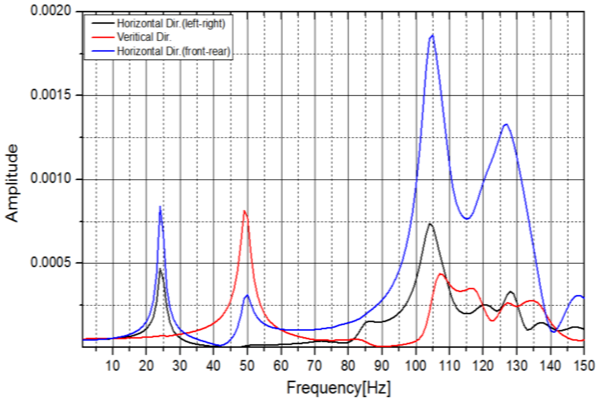

Fig. 18 Frequency-Amplitude plot

V. CONCLUSION

These days the importance of high speed robots is increasing because the unit cost of production has to be decreased. For this reason, the market of the high speed parallel robot is increasing. In this research, a high speed parallel robot has been developed. In this paper, the design process and the developed analysis tools to help the design of a high speed parallel robot were introduced.

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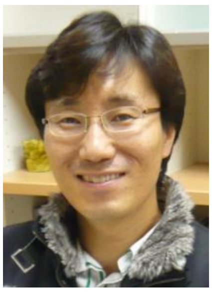

Chanhun Park received PhD degree in Mechanical Engineering from KAIST, KOREA. He has been working for Korea Institute of Machinery and Materials (KIMM), Korea, since 1996, where he is currently a principal researcher. His research fields include design and control of high speed parallel robot system. He is also interested in human-robot cooperation and design and control of dual arm robot manipulator for industrial applications.