Experimental results of a high speed dynamically balanced redundant planar 4-RRR parallel manipulator

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When manipulators (i.e. robots, mechanisms, machines) run at high speeds, forces and moments for the acceleration of mass and inertia lead to considerable vibrations of the base. These vibrations are transmitted to, for example, measuring and processing equipment that is mounted on the same base, affecting the manipulator performance. Base vibrations also lead to, among others, increased noise, wear, and fatigue, and to reduced comfort for hand-held tools.

To reduce the influence of base vibrations, (active) damping can be applied or waiting times can be included in the motion cycle to wait until vibrations have died out. Another solution is to design the manipulator to be dynamically balanced. Of a dynamically balanced manipulator the net dynamic forces (the shaking forces) and the net dynamic moments (the shaking moments) the manipulator exerts to the base are zero for all motion. Motion of the manipulator then does not cause the base to vibrate.

A disadvantage of dynamic balancing is that often a considerable amount of mass and inertia is added [1]. This may be the reason that up to now little research has been done on the balancing of parallel manipulators. Various studies, however, have led to guidelines for low mass and low inertia dynamic balancing [2]. Based on these guidelines a high speed balanced redundant planar 4-RRR parallel manipulator was designed [3] and a prototype was developed and tested.

In this paper the experimental results of the balanced 4-RRR manipulator will be presented. Since no experiments for high speed dynamically balanced manipulators are known, these are exclusive results. In addition to the shaking forces and the shaking moment, also other issues will be addressed such as the driving torques, the bearing forces, the sensitivity for balance inaccuracies, and the influence of payload. The experimental results are compared with the results of the same manipulator being unbalanced.

References


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Figure 1: The redundant 4-RRR parallel manipulator balanced with four counter-masses (left, patented) is supported by four cables to float freely within the horizontal plane. A 6-DoF force-torque sensor is mounted in between the manipulator base and the fixed base (right) to measure the resulting in-plane shaking forces and shaking moment.

<table>
<thead>
<tr>
<th>Test trajectory (2.6g)</th>
<th>Unbalanced (2.6g)</th>
<th>Balanced (2.6g)</th>
<th>Balanced 10.3g</th>
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<tbody>
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Figure 2: For 2.6g motion along the symmetry axes (see column 1) the balanced manipulator is compared with the same manipulator without counter-masses which then is unbalanced. The measured shaking forces and shaking moment of the unbalanced and of the balanced manipulator are shown in columns 2 and 3, respectively. While for the unbalanced manipulator shaking forces up to 300 N are measured, the shaking forces of the balanced manipulator are just above the sensor noise at about 5-6 N. Also the shaking moment of the balanced manipulator is considerably lower than that of the unbalanced manipulator. Column 4 shows for the balanced manipulator for 10.3g motion the measured shaking forces being up to 30 N and the measured shaking moment being up to 0.44 Nm. This means that for four times higher accelerations, the shaking forces and shaking moment of the balanced manipulator are about ten times lower than those of the unbalanced manipulator.