CONTROLLER CONCEPT FOR A HIGHLY PARALLEL MACHINE TOOL

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1. Introduction

Modern cutting processes create a high demand for new machine tool concepts with improved mechanical stability and better dynamic behaviour. A main focus of the Institute for Production Engineering and Laser Technology at Vienna University of Technology is on the design of machine tool structures with parallel kinematics. The first parallel kinematics machine tools were built with a degree of parallelism of one, e.g. Quickstep and Quickstep Neon [1]. This implies that there are as many drives in the machine as there are degrees of freedom for the tool and the Tool Centre Point (TCP), respectively. The newly developed machine tool "X-Cut" (refer to fig. 1) has a degree of parallelism of two, incorporating four drives for the X-Y planar movement whereas in simple scissors kinematics only two drives are necessary [2]. Due to the complex behaviour of the kinematics structure, new control strategies are necessary to avoid undesired restraining forces and thereby high driving forces and position inaccuracies.

Fig. 1: Machine tool X-Cut

2. X-Cut concept

X-Cut uses hardware from Austrian control system vendor, Bernecker & Rainer. In detail, an APC 620 with a CNC Panel PP480 in terminal mode as HMI, five ACOPOSmulti's as positioning axis controllers and an ACOPOS servo drive as spindle controller.

The software solution is based on the CNC software from B&R expanded by coordinate transformation, compensation tables and control algorithms. In the software, the G-code is interpreted by the ARNC0, which outputs the interpolated x, y and z coordinates for each program cycle (400μs). These coordinates are to be calculated with the indirect transformation for the carriage position of each strut (figure 2).

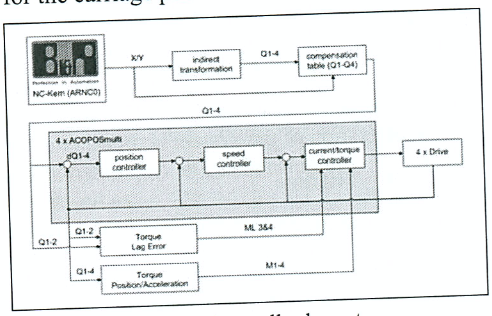

Fig. 2: Controller layout

Additionally to the position, a supplemental torque depending on position, velocity and acceleration is sent to the torque-controller part of the ACOPOSmulti. This control cycle is directly set before the drive and has therefore the shortest reaction time.

Essentially two strategies are possible:

- Force driven additional axes
- Position driven additional axes

2.1 Strategy 2-Position 2-Force

In this particular case, axes 1 and 2, which are on the left side of the structure, are position controlled and axes 3 and 4, on the right side, are force driven. The advantage of this strategy is that inaccuracies in the structure aren't inducing restraining forces, because the force on struts 3 and 4 are not dependent of the position error.

2.2 Strategy 4-Position

All four axes are position controlled. This strategy imposes a higher demand on the machine calibration because even a small position inaccuracy leads to high forces in the structure and no power reserve for the movement exists.

3. Predefined torque calculation

The predefined torque is composed of different individual values. It is possible to activate each compensation on its own.

- Static Compensation

A torque which generates a defined force on each strut in an axial direction. Only gravity and geometrical dimensions are taken into account.

- Dynamic Compensation

Additionally to the static torque, the acceleration of the system is used.

- Friction

The load dependent friction of the carriages is added.

- Lag error transfer

At a force controlled axis, the force is independent of the position deviation of the axis. In order to achieve also a position dependent torque without the influence of structural inaccuracies, the position deviation of axes 1 and 2 are transformed to axes 3 and 4. This deviation is multiplied by a K_v-factor and added to the predefined torque. This corresponds to a simple P-Controller with a dead time element.

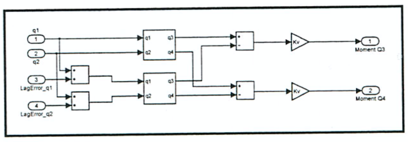

Fig. 3: Lag error transfer

4. Experiments

For each predefined torque, experiments were performed on the machine with different parameters and paths. During the tests the driving torque and the lag error was logged by the control unit.

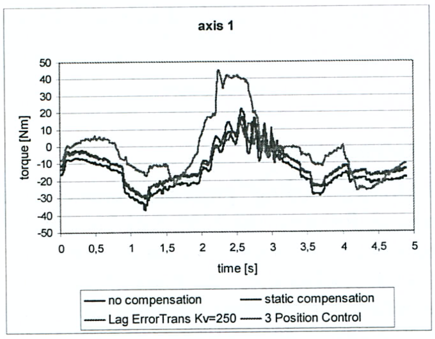

Fig. 4: Circle path – Torque axis 1

An example for the torque on axis 1 during a circular motion with 20 m/min feed rate is shown in figure 4.

5. Acknowledgements

In general the charge of each drive can be reduced by the predefined torques. Thereby higher feed rates and acceleration are possible. With the 2-Position/2-Force controlled strategy, oscillations are generated around the extended position of the position driven axes. This effect could be eliminated by a switch of the position dependent axes from one side-pair of struts to the other. The requirement of this change is dependent on whether the x/y-position of the TCP is close to the singularity point. With the 4-position control strategy, there is no oscillation, but the generated torques are greater to offset the restraining forces in the structure. With enhanced predefined torque algorithms it will be possible to divide the charge uniformly to all axes and increase the maximum feed rate, acceleration and accuracy.

6. References

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[2] Mikats, T., Puschitz, F., Bleicher, F., New Machine Tool Concept 'X-Cut [online] http://www.br-automation.com/files_br_com/Mikats09_New_Machine_Tool_Concept_X-Cut.pdf (2009)