Start-up and Control Operations for Top Milling Machine Tools

Belda, K.

Institute of Information Theory and Automation AS CR, Prague, Czech Republic

Keywords:
Automation, Machine tool, Calibration, Predictive control

Abstract

Top milling machine tools are widespread in industrial production for their broad usability in a flexible production. However, their concept, represented by a fixed rotary shank tool in a stationary or a displaceable spindle and sliding carriages supporting workpiece gripper, is limited in the motion dynamics and coordination. It can be overcome by a different machine construction based on parallel kinematic concept enabling main operational tool-spindle to move in all axes of 3D space simultaneously. The contribution deals with a suitable solution of homing, calibration and control operations for top milling machine using just idea of parallel concept.

1 Perspectives in machine tools

Top milling machine tools, due to their broad usability in a flexible production, are quite widespread in industrial production. They offer a simple construction, ensuring reasonable accuracy as dedicated machines with a certain level of a spatial flexibility as robotic systems. However, their concept represented by a fixed rotary shank tool (milling cutter) in a stationary or a longitudinally displaceable spindle and sliding carriages supporting workpiece gripper (fixture) is limited in the motion dynamics and coordination. This limit can be overcome by a different machine construction based on parallel kinematic concept [1], [2]. It enables tool-spindle (main operational spindle) to move in all axes of three-dimensional space simultaneously. Then, the sliding carriages are only auxiliary or they are replaced by a fixed working surface for fixing of the workpieces.

In general, the robot machines based on parallel kinematic structures can be simply characterized as movable truss constructions or as movable platforms supported by several links, where platforms serve as a place for a tool or for a gripper. These structures represent closed-loop constructions, flexibility (dynamics) of which allowing high productivity follows from possible small number of moving masses. Therefore, in comparison with serial types, they may offer higher stiffness and dexterity. This feature is given by the fixing almost all drives directly on the basic frame without loading of movable parts of the robot construction. It contributes to the decrease of inertial forces. However, a larger number of the links and passive joints often require more sophisticated procedures in a robot adjustment, start-up and real control process.

All operations should ensure a co-action of each drive participating in robot motion. The start-up operations (homing, calibration) are limited by unknown initial robot state, which is detected during them. Once the robot state is determined at least roughly, then the drive co-action can be ensured. Since start-up operations have no so strict time limitation, they may be performed in such a way not to come in undesired states. The time conditions have to be taken into account during the main operations (control, production operations), which follow from requirements of real technological process.

Conventional local control strategies (e.g. cascade drive control) have no energy optimization. It is a limiting factor of a robot capacity. In the case of parallel robots, it may produce undesired antagonistic drive behavior i.e. behavior without necessary drive cooperation. The antagonism, i.e. drive mutual fighting, is caused by the presence of interrelations among the individual drives through parallel links and appropriate movable platform. The conventional control cannot consider these interrelations and therefore it does not represent economic and safe solution. To avoid mentioned undesirable states, some model describing energy decoupling in the robot structure is needful. However, when some model is available, then global model-based control strategies [4] are more efficient. They can provide design of control actions, which are optimized for given robot structure.

The organization of this contribution is the following. At first, homing and calibration operations intended for planar parallel robots are discussed. Thereafter, the control issues relating to the parallel structures including comments on drawbacks of conventional approaches are explained. All procedures being described here are documented in several representative examples arising from their implementation on one real prototype of parallel kinematic top milling machine tool.

2 Start-up operations

Start-up operations, homing and calibration are supporting operations, which are necessary for proper start and use of robotic machine tools. Its importance consists in guarantee of production repeatability and precision. They are performed in one shot or regularly prior to each start of production or machining cycle. The following subsections explain the operations in view of parallel kinematic robot structures.

2.1 Homing

An operation of homing represents set of actions automatically leading the all robot elements from initial generally unknown position (i.e. arbitrary position from a robot workspace) to predefined known deterministic position, so-called home position.

In the case of parallel structures, which can be moreover redundantly actuated, the homing is limited by kinematical relations through chained robot links and has to be proceeded for all drives simultaneously. Individual homing of each drive is not possible. It could cause collisions of the robot links and unsafe robot motion, which can lead to the damage of the robot and its neighbourhood.

In general, considering incremental position sensors, to determine initial robot position, some 'homing' marks are commonly used (see Figure 1). They are usually fixed to the movable parts connected with drives.

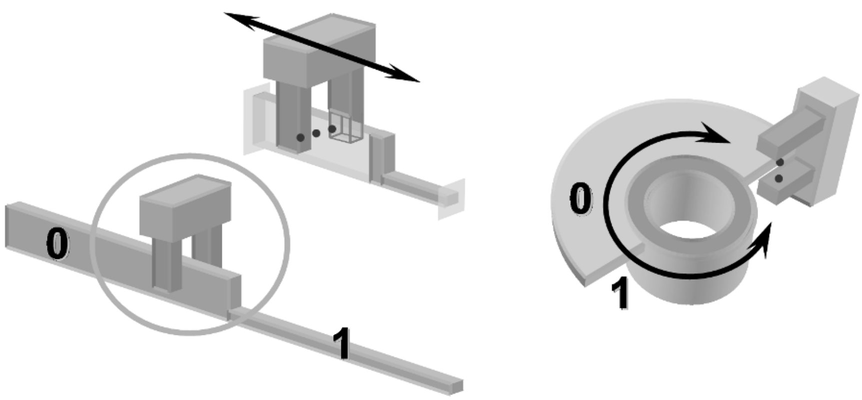

Figure 1: *Examples of homing marks for both linear and rotational drives*

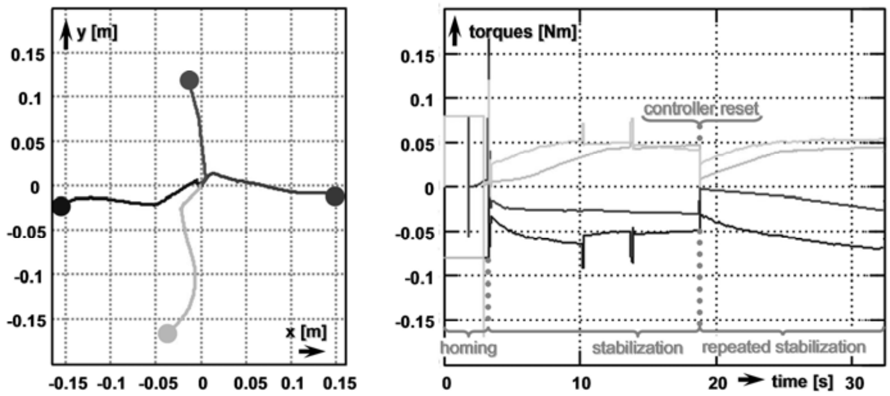

Figure 2: *Example of four real trajectories from random border points to the central home position and time history of real homing and calibration of the robot structure "Moving Slide".*

However, by the simultaneous homing, the individual drives reach the home position in different time. When one drive reaches mark change, it should be stabilized in the mark neighbourhood. Nevertheless, its stabilization has to be soft not to restrict other drives to reaching the mark changes. After the change of all marks, it is necessary to watch over the all stabilizing actions, especially in case of redundant robot actuation, where mutual drive fighting may appear.

2.2 Calibration

Calibration is an operation of identifying of real geometrical parameters in given kinematical structure relative to the position and orientation of its links and joints. The first phase called mechanical calibration is more or less equivalent for both serial and parallel robots. The second phase, a software calibration, actually local sensor calibration is different. In comparison with the homing procedure of parallel robots in previous section, that calibration phase has to pass individually for each sensor and appropriate drive by reason of accuracy. Contrary to serial robots, where the movement during the calibration is not limited except for occurrence of link collisions, the movement of each drive is strictly limited to small vicinity of selected representative positions (e.g. home position), since larger movement causes undefined movement of a movable platform, links and other robot elements. Thus, this operation is discontinuous.

After each sensor calibration, the homing operation like has to be executed in order to provide the same initial conditions for other sensors waiting for calibration. Single calibration procedure inclusive initial homing procedure for parallel kinematic structures e.g. with n drives and their appropriate sensors can be formulated by four steps as follows:

- Step 1. Let the homing operation is done.
- Step 2. Let the all drives slowly change the marks and stop immediately after that change on the predefined mark side identical for all cases.
- Step 3. Let the i^{th} drive is moved back and when the new drive sensor hit is appeared, let the sensor value is reset to its new origin, values of which correspond to real physical coordinates for given position.
- Step 4. Let the procedure goes to Step 1 and all four steps are repeated for other drive and sensor pairs up to state when all sensors are reset to real values.

The correctness of the operation can be verified by backward controlled motion with the reference values recomputed from record of sensor data and inversed in their own direction. The robot, which starts in this backward motion in known home position, should reach accurately the initial unknown position. This proof can be done due to the known starting home position.

Moreover, the robot can be already controlled in both coordinates systems: drive coordinate system or operational system. Due to the known relation among appropriate sensor values and real robot position, the direct and inverse kinematical transformations are computable even for redundantly actuated parallel structures. The mentioned kinematical transformations enable user to use the both coordinate systems equivalently [3].

Another possibility, in the case of redundantly actuated robots, is on-line calibration. Since all drives (adequate and redundant) are equipped with drive sensor, then during each motion of the robot, there is a redundant number of measurements. The assembled equations of constraints for certain number of robot positions can be solved for both robot dimensions and initial positions. This approach enables the redundantly actuated parallel structures to be calibrated on-line during their operations without using any external equipment or breaking their work. For specific kinematic configurations (e.g. structure ‘Moving Slide’ introduced in section 4), this possibility can represent direct accurate position determination of a machine working point, then the machine movable platform, without necessity of length calibration of all robot links.

3 Control operation

The general issue of the control operation is tracking the desired trajectory given by machined shape of workpiece. To design suitable control, the following fact has to be considered. The robotic structures represent nonlinear multivariate systems, dynamics of which is relatively fast in comparison with computation time for control actions. For that reason, the discrete methods are considered due to possibility to ensure the finite computation time of the control.

The control can be solved either on local level by design of independent control of the drives as servos, or on global level by design of control for the whole robot structure exploiting its mathematical description. For design of whatever level, detail knowledge of the machine is essential and it is usually represented by mathematical description.

3.1 Conventional control design

The conventional control design based on PID/PSD feedback control considers the robots, machine tools as a set of single-input single-output drive subsystems. The mutual interactions are taken into account as disturbances entering individual subsystems. In the case of parallel robotic structures, possibly redundantly actuated, the unproductive part in I/S channels of PID/PSD controllers can occur. It is caused by inaccuracies in the structure, i.e. drive coordinates determined from operational coordinates in some cases cannot be attainable. To damp this undesired property, the specific reduction projection based on Jacobian matrix can be involved simply in basic PID/PSD structure see Figure 3.

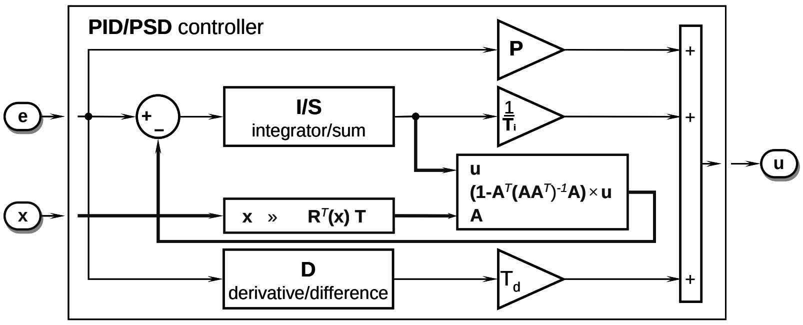

Figure 3: Modified PID/PSD controller structure

3.2 Advanced control design

The advanced control design in general is based on mathematical model and some criterion [4], [5]. That way, it globally optimises control actions in the whole robot structure point of view. Due to the model, the undesired properties of conventional control discussed in previous subsection do not occur.

One of representative strategy is predictive control. It represents a multi-step control design based on the equations of predictions and the local repetitive minimization of quadratic criterion. Control circuit including other controllers is shown in Figure 4.

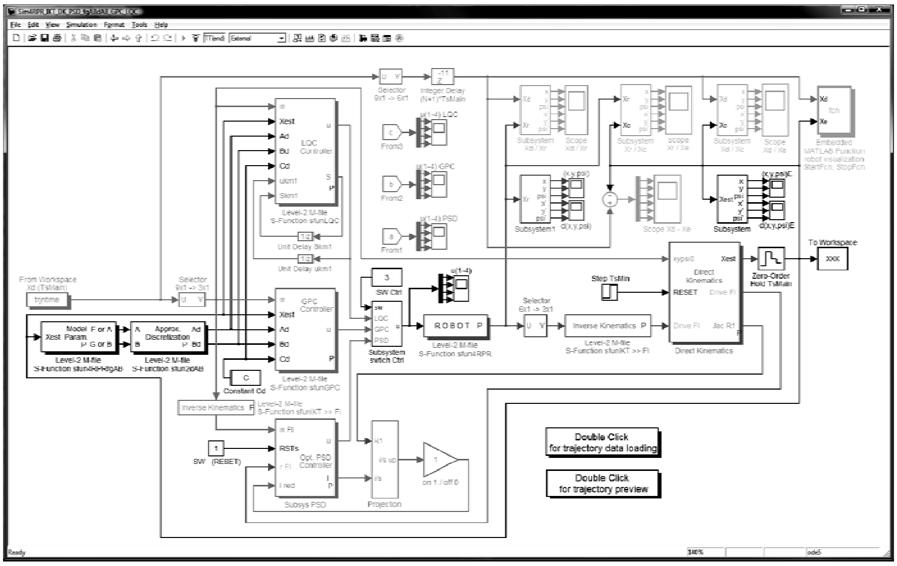

Figure 4: *Comparative Simulink model with conventional and advanced controllers*

4 Top milling parallel structure “Moving Slide”

In this section, the one specific parallel robot structure called “Moving Slide” will be introduced (Figure 5). It is intended for top milling machine tools. Main spindle of the machine serving for milling cutters is located in the centre of a movable platform. The main coordinates are axis coordinates in plane. Remaining orthogonal axis coordinate can be set independently or fixed.

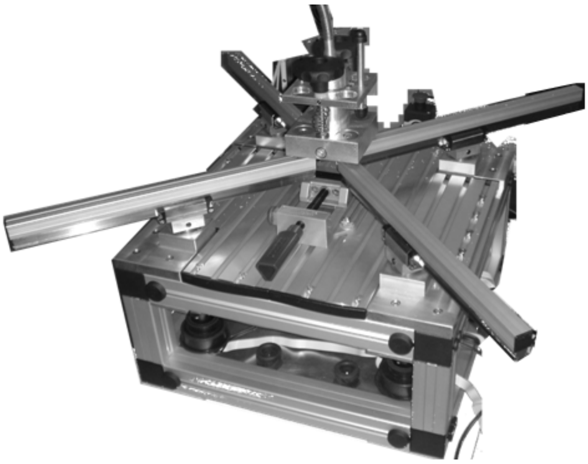

Figure 5: *Top milling parallel robot structure “Moving Slide”*

The robot structure is driven by four equivalent rotational drives without whatever motion screws or nuts. The drives are fixed in the corners of the square workspace.

5 Conclusion

The paper presents new perspective robotic structure for top milling machines including discussion on start-up and control operations for parallel structures in general.

Literature

[1] *Tsai, L.-W.:* Robot analysis, The Mechanics of Serial and Parallel Manipulators*, John Wiley & sons, Inc., New York, 1999.*

[2] *Merlet, J.-P.: Parallel Robots, Springer, Dordrecht, 2006.*

[3] *Böhm, J., Belda, K., Valášek, M.: The Direct kinematics for path control of redundant parallel robots. Advances in Systems Science. WSEAS, 2001, 253-8.*

[4] *Rossiter, J., A.: Model-Based Predictive Control, CRC Press, London 2003.*

[5] *Belda, K., Böhm, J., Valášek, M.: Predictive Control Applied to Planar Parallel Robots. Preprints of the 16th IFAC World Congress, Prague 2005, 6 pp.*