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STRUCTURAL CONFIGURATION METHODS FOR MACHINE TOOLS

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Abstract: *The papers deals with description of a generating method for structural configuration of machining centers, considering in detail a vertical machining center with three axes. Starting from a structural configuration of an existing machining center the basic structural configuration is established. A tree-graph corresponding to this structure is generated. It consists of a sequence of structure elements connected by joints (R-revolution, P- prismatic). By combining the elements and joints one can obtain all possible variants of configurations. Applying some criteria the optimum variant of structural configuration is obtained.*
Key words: *machining center, automatic tool changer, structural configuration synthesis, graph representation, motion axis.*

1. INTRODUCTION

Modern machine tools, especially those integrated in flexible machining cells and flexible machining systems and some of those included in the group of specialized machine tool, are of machining center type. They have specific systems such as tool magazine and automatic tool changer [1], [3], [4], [10]. The system (ATC) has 5 possible configurations depending on machine tool type and destination, kinematic structure and mechanism construction, kinematic chains, driving and control, layout on one or more structure elements, position of the main spindle, capacity and tool magazine type, possibility of modularization [6], tool change necessity, running under precision conditions, good reliability and static and dynamic behavior. The use of ATC is extended through their modularization [5], [8], [10].

The cycles of tool changing are composed of simple motions: revolution and prismatic. Their succession is mainly determined by the position of tool axis in magazine and main spindle axis, distance between magazine and main spindle, position of ATC system joints.

2. STAGES OF STRUCTURAL CONFIGURATION GENERATION

Depending on the ATC type, machine tool structure, and position of the ATC components in regard with machine tool elements, all structural configurations of the machining center can be generated.

Among the motion characteristics one can emphasize that the relative motion of the table with respect to the spindle head is done along the three axes (*X*, *Y*, *Z*) generating the working volume. The axes of the spindle and tool magazine can be either parallel or

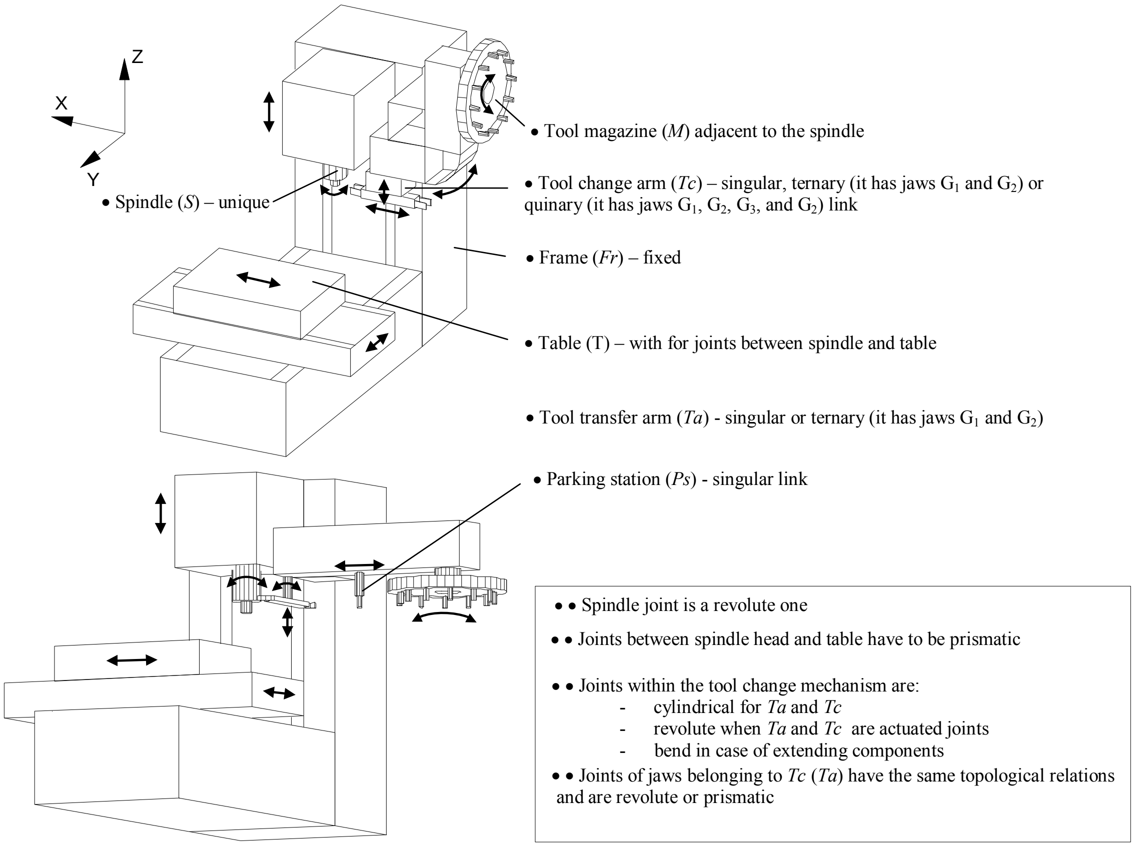


Fig. 1. *Structural configurations of three-axes vertical machining centers*

perpendicular. The transfer arm *Ta* and tool change *Tc* can have many structural and kinematic variants. The parking station *Ps* achieves rotary or linear motions for translating or orienting the tool axis.

The following stages for structural configuration of open structures can be considered:

a. Choosing an existing machining center and analyzing the structure and motion characteristics.
b. Representation the existing machining center structure as a tree-graph.
c. Generalization of machine into a generalized tree-graph.

d. Synthesis of all possible tree-graphs with given numbers of vertices (structure elements) and edges (joints).
e. Applying topological constraints to all tree-graphs and choosing the workable ones.
f. Obtaining the atlas (all structural configurations) of machining center allocating the axes and applying certain motion constraints.

More details of the stages a, b, …, f and theoretical support are given in [2].

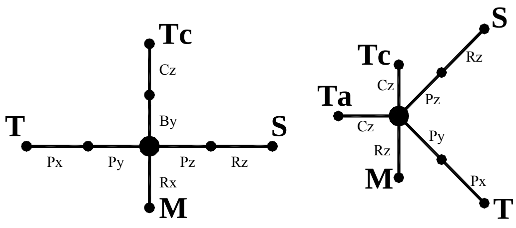
3. CONFIGURATION OF VERTICAL MACHINING CENTERS

Regarding this type of machining center, from the point of view of machine tool, we take in consideration the form and topology of structural elements, main spindle axis position (vertical), numerical controlled axes, structure element sizes, working space (size and position). Regarding the ATC, we consider the form, position and capacity of tool magazine, position and movements of tool transfer arm and too change arm (for the variants including them). The parking station characteristics have to be taken in consideration for machining center types including it (not the studied case).

The reference system of the machine is well known according to ISO [9]. The block schemes of the machines and their component motions are shown in fig. 1. Taking in consideration the machine tool axes, structure components and their motions the vertical machining center can be described through representing the links and joints by vertices and edges [2]. According to this representation the structural elements of the machine are vertices with the names given in fig. 1 (*S*, *T*, *Fr*, etc.), and joints are represented by edges named Revolution (*R*), Prismatic (*P*), Cylindric (*C*), Bend (*B*) that have a subscript corresponding to the motion axis. In fig. 2 the tree-graphs corresponding to the machining centers shown in fig. 1 are presented.

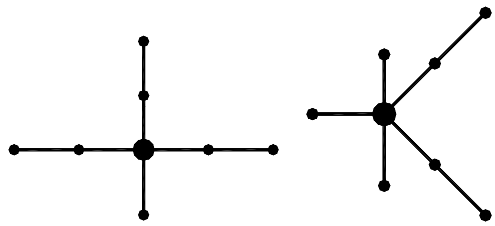
There is a large variety of structural configurations given by the feasible combinations between machine tool and ATC. The comprehension of all possibilities first imposes a generalization of the machine tool type from the point of view of three-graph representation, starting from the particular three-graphs (fig. 2). The principles and rules of generalization are shown in detail by Yang and Hwang mentioned in [2]. Thus, in fig. 3 the generalized graphs of the particular graphs in fig, 2 are shown. A generalized tree-graph is characterized by the number of vertices N and number of edges $J = N - 1$ valid for open structures as in case of machine tools in classical configuration. On the basis of the generalized tree-graph all feasible graphs are generated.

The possible tree-graphs result through combinations of vertex and edges. As an example, for a structure with 7 vertices 11 tree-graphs will be derived. Only 3 of them (fig. 4) have a corresponding vertical machining center structure. If the number of vertices is 8, the number of graphs is much greater, only 8 of them (fig. 5) having practical application.



a **b**

Fig. 2. *Tree-graphs of the machining centers shown in fig. 1*



a **b**

Fig. 3. Generalized tree-graphs of the particular graphs from fig. 2

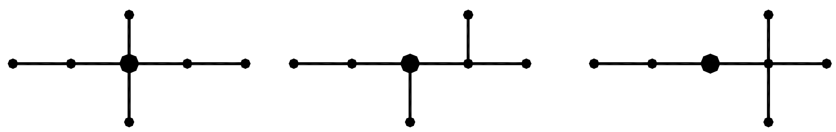


Fig. 4. *Selected graphs for a structure with 7 vertices*

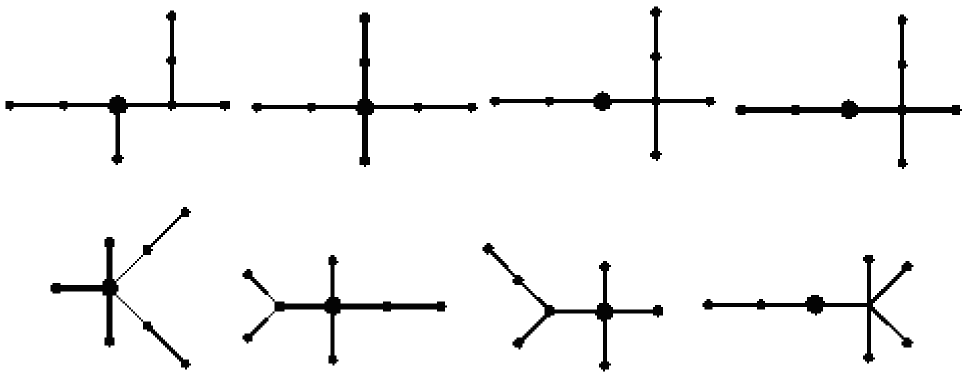
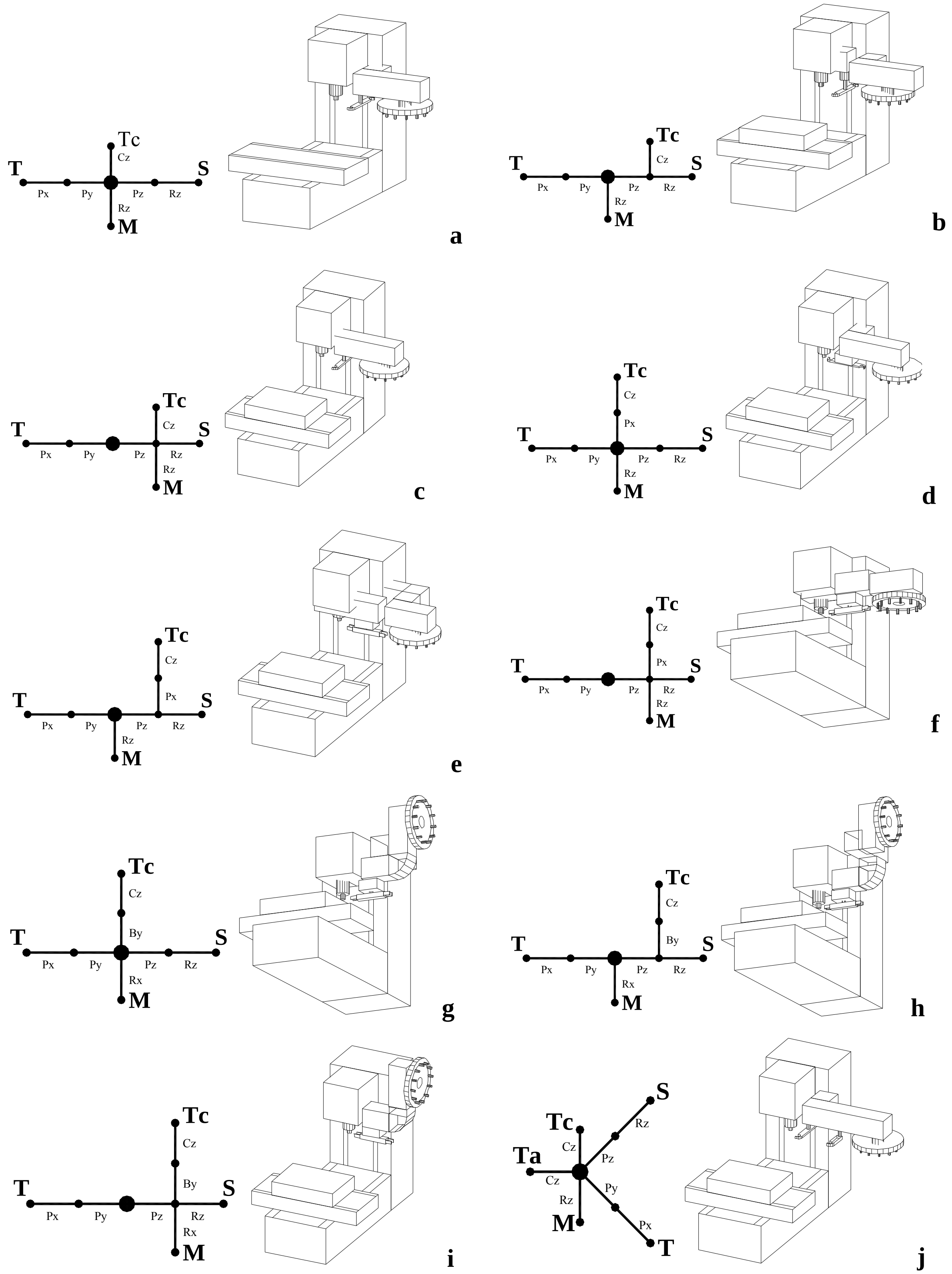


Fig. 5. *Selected graphs for a structure with 8 vertices*


Tc Cz T Px Py Pz Rz S Rz M
a
Tc Cz T Px Py Pz Rz S Rz M
b
Tc Cz T Px Py Pz Rz S Rz M
c
Tc Cz Px T Px Py Pz Rz S Rz M
d
Tc Cz Px T Px Py Pz Rz S Rz M
e
Tc Cz Px T Px Py Pz Rz S Rz M
f
Tc Cz By T Px Py Pz Rz S Rx M
g
Tc Cz By T Px Py Pz Rz S Rx M
h
Tc Cz By T Px Py Pz Rz S Rx M
i
S Rz Tc Cz Pz Ta Cz Py Rz M Px T
j

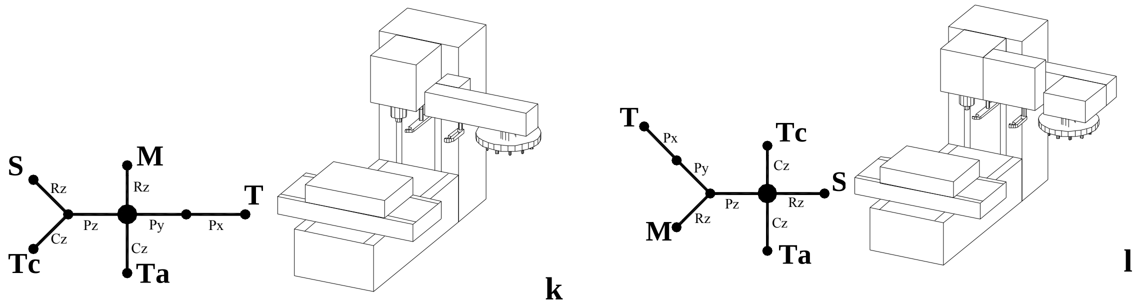


Fig. 6. *Schematic representations of vertical machining centers* (*first part*)

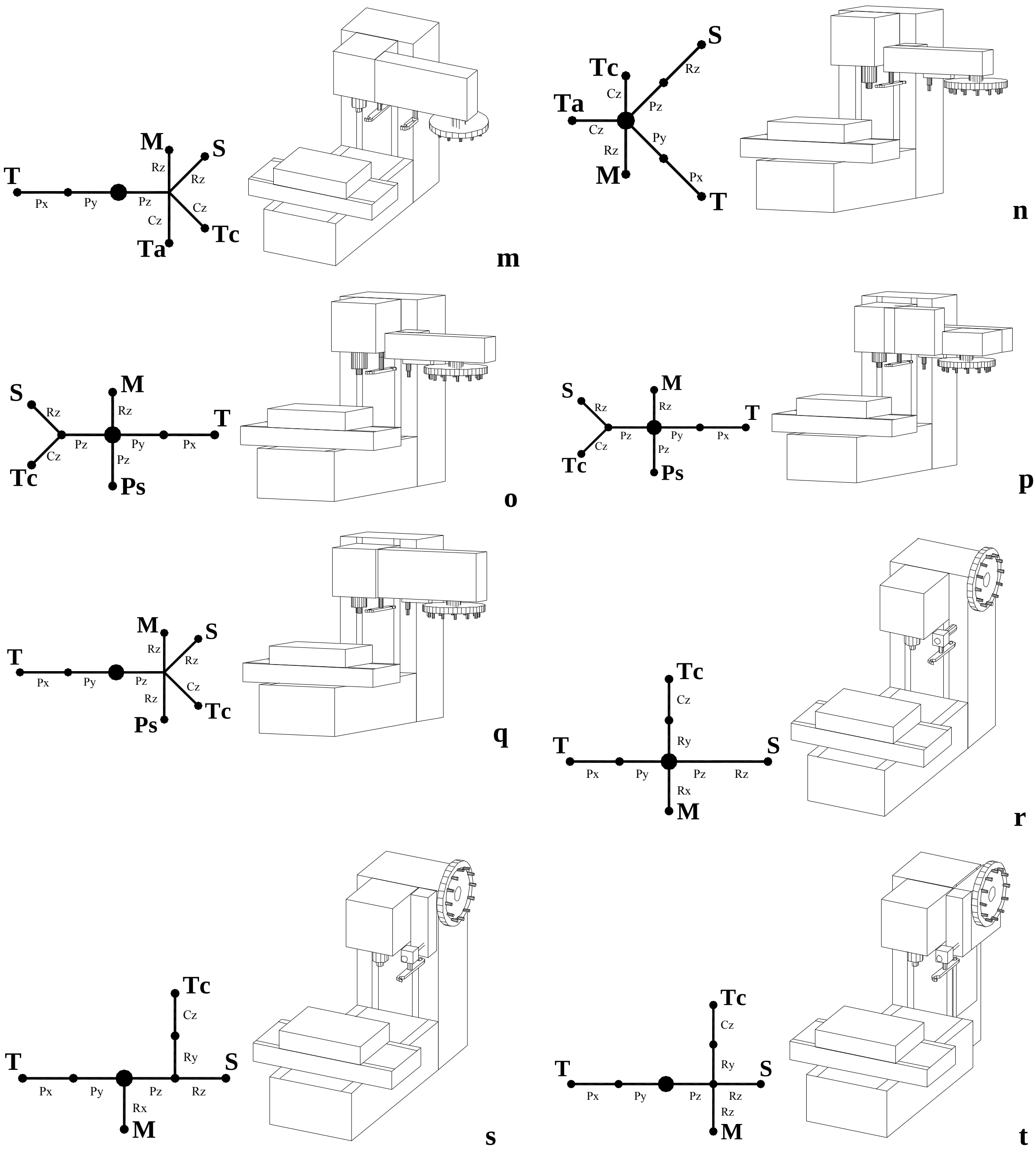


Fig. 7. *Schematic representations of vertical machining centers* (*second part*)

The selection of variants with practical application is based on topological constrains that are design requirements specific to the considered machine tool type. For a vertical machining center with three axes the following requirements have to be taken in consideration:

- For an ATC having a structure including only a *Tc* the tre-graph has 7 vertices, for a structure with *Tc* and *Ta* or *Tc* and *Ps* it has 8 vertices, for a structure with *Tc*, *Ta*, and it has 9 vertices.
- A vertex is allocated to spindle *S*, the edge incident to *S* being a revolution couple.
- A vertex is allocated to the table *T* and has to be at a distance of 4 edges from *S*.
- A vertex is allocated to the frame *Fr* which is fixed.
- A vertex represents the tool magazine *M* associated to spindle *S* due to the tool transfer between them.
- *Ta* is connected through 1 or 3 edges (the vertices G1 and G2 have to be implemented).
- *Tc* is connected through 1, 3 (G1 and G2 vertices) or 5 (G1, …, G4 vertices) edges.

The components G1 , …, G4 define the tool gripping mechanism belonging to *Ta* and/or *Tc*.

In [2] one presents other rules of link and joint assignment. The notations on each tree-graph are made on each vertex and edge so that the specialized variants are obtained.

It is taken in consideration the rules of assignment of links and joints. For example, *S*, *M*, *Ta*, and *Ps* are pendant vertices; if *M* is of disc or chain conveyor type the edge is a revolution couple *R*; the table *T* is connected to the frame *Fr* through two prismatic couples *P*.

The last stage of the synthesis is the assignment of axes and direction to the joints on the selected specialized tree-graphs. In this stage, the motion constraints are applied (for example the revolution axis of *S* is always *Z*; the axis of *M* is parallel or perpendicular to the axis of *S*; the table *T* moves on *X*, *Y*, and *Z* relative to the spindle head *SH*, etc.). The variants of tree-graphs having associated possible block schemes from the practical point of view are presented in fig. 6 and 7. The first 3 variants correspond to the structure with 7 vertices, the rest of 17 corresponding to the structure with 8 vertices.

The analysis of the 20 variants considering constructive, technical, and economic criteria leads to the selection of that variant which passes in the stage of machine tool design.

4. CONCLUSIONS

The paper presents the application of the tree-graph method of structural configuration generation in vertical machining centers starting from the study of the ATC types and their association with existing machine tools. For a vertical machining center with three axes, 3 structural configurations for system with 7 vertices, and 17 structural configurations for 8 vertices were derived. The method can be used in the synthesis of other types of machine tools, industrial robots and other open mechanical structures. Also, the method can be integrated in the approach of machine tool reconfiguration.

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