Title:
Optimal Sequencing Method for Machining Cells of Complex Structural Parts based on Process

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Introduction:
The sequencing of machining cells is a key problem in the NC machining automatic programming for complex structural parts. The sequencing of the machining cells must meet the process requirements and ensure that the tool path is short. In order to improve the rough machining efficiency of complex parts, Zhang et al. [4] established a machining sequence optimization model, and used the tabu search algorithm to solve the model, but this method is only for independent features and cannot Handle intersecting features. For aircraft structural part, Xu et al. [3] proposed a chaotic simulated annealing algorithm to optimize the machining tool path of features with only one tool. Zheng et al. [5] used a genetic algorithm to reconstruct the machining cell for the intersecting features of complex pockets. Huang et al. [2] optimized the tool path by using a hybrid algorithm of ant colony optimization and tabu search for the process plan reuse problem of complex parts with intersecting features. From the perspective of energy saving, Bi and Wang [1] optimize the machining processes by establishing the energy models based on kinematics and dynamics of machine tools with considerations on both the material flow and tool flow mutually. The existing research rarely considers the overall sequencing of machining cell from both macro and micro levels. Therefore, this paper proposes a process-based optimization sequencing method for machining cells: at the macro level, the overall machining sequence is realized based on the process described by the process scheme; at the micro level, the sequencing of tool-related machining cells is emphasized. Finally, the sequencing method takes into all the key factors from the process to machining step and cutters, etc., in the entire CNC machining process.

Overview of the Process-based sequencing method:
The technological process is the process of machining parts in the specified order according to the given working procedure, working step and process resources (cutters, machine tools, etc.) under the guidance of the process scheme. As shown in Fig. 1, according to the technological process, the machining cells are ordered at the macro level and the micro level (cutter level). Among them, at the macro level, the macro process described by the process scheme is followed, including the machine tool to the cutter node; at the micro level, the machining cells associated with the cutters are grouped in multiple levels, and these cutter groups are sorted according to the technological process.

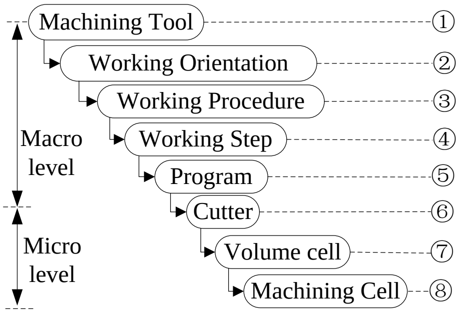

Fig. 1: Sequencing hierarchy diagram based on process.

Grouping of machining cells:

As shown in Fig. 2, according to a given process scheme, a set of tool sequences can be obtained, each cutter in the sequence is associated with a group machining cell, and this group of machining cells constitutes a "first-level group". In the first-level cell group, in order to make the part machining process meet the technology process requirements, the target machining cells and the real-time supplemented machining cells are separated to form a "second-level group". Since there are many types of supplemented machining cells, and different types of supplemented machining cells need to be processed in a centralized manner, the supplemented machining cells are grouped according to the type of working step to form a "three-level group". In addition, due to the special requirements of the process, some machining cells need to be grouped according to special process requirements. Take layered roughing as an example, the machining cells in each layer can form a group, a "four-level group".

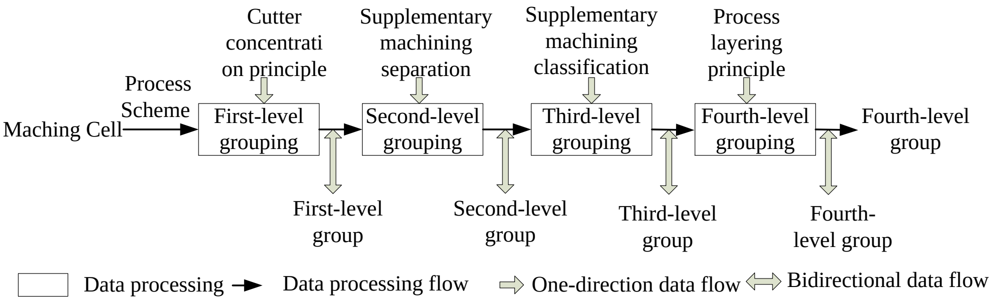

Fig. 2: Grouping of machining cells.

The above grouping can be defined by the following model:

$$S = \bigcup_{1}^{m} S_1^i = \bigcup_{1}^{m}\bigcup_{1}^{n} S_2^{ij} = \bigcup_{1}^{m}\bigcup_{1}^{n}\bigcup_{1}^{h} S_3^{ijk} = \bigcup_{1}^{m}\bigcup_{1}^{n}\bigcup_{1}^{h}\bigcup_{1}^{b} S_4^{ijkl} \quad (1)$$

Among them, S is all machining cells, S_1^i is the machining cell group included in the i-th cutter in the given cutter sequence of the process scheme. S_2^{ij} is the j-th second-level cell group in S_1^i, which may be the target cell group or the supplementary machining cell group. S_3^{ijk} is the k-th third-level cell group in S_2^{ij}, which may be any working step type in the previous process. And S_4^{ijkL} is the l-th fourth-level cell group in S_3^{ijk}.

Sequencing of machining cell groups:

After the machining cells are grouped, the machining cell groups are sorted based on the technological process. The rules are as follows:

Macro-sequencing rule: Let $S_1^1, S_1^2 \ldots, S_1^m$ be the initial sequence of all first-level cell groups and be disordered. According to the depth traversal of the process scheme, the processing sequence g_1, g_2, ..., g_m is obtained, in which the tool of g_i is t_i, the program is p_i, the working step is s_i, the working procedure is r_i, the working orientation is o_i, and the machine tool is m_i, $1 \leqslant i \leqslant m$. Set t_j is the cutter of machining cell group S_1^j, the program is p_j, the working step is s_j, the working procedure is r_j, the working orientation is o_j, and the machine tool is m_j. If $t_j=t_i$, $p_j=p_i$, $s_j=s_i$, $r_j=r_i$, $o_j=o_i$, $m_j=m_i$, then S_1^j should be placed in the i-th position of the new sequence, j=1,2,...,m, and finally form a new first-level cell group sequence $S_1^{1'}, S_1^{2'} \ldots, S_1^{m'}$.

Cutter-layer sequencing rule: Let the machine tool be m, the station be o, the working procedure be r, the working step be s, and the program to be p, the complementary machining cell group associated with the tool t_i is S_2^{i1}, the target cell group is S_2^{i12}, and S_2^{i1} can be divided into several initial sequences of the third-level cells $S_2^{i11}, S_2^{i12}, \ldots, S_2^{i1n}$, $1 \leqslant n$. Under the premise that the machine tool is m and the working orientation is o, the pre-procedure sequence of working procedure r is r_1, r_2, ⋯, r_l, $1 \leqslant l$, and the working step sequence of r_k is s_{k1}, s_{k2}, ⋯, s_{kh_k}, $h \geqslant 1$, $1 \leqslant k \leqslant l$. Under the working procedure r, the previous working step sequence of the working step s is s_1, s_2, ⋯, s_b. It can be seen that under the premise that the machine tool is m and the working orientation is o, the previous working step sequence of the working step s is $s_{11}, s_{12}, \ldots, s_{1h_1}, s_{21}, s_{22}, \ldots, s_{2h_2}, \ldots, s_1, s_2, \ldots, s_b$. Extract the working step type of the compensated machining of $S_2^{i11}, S_2^{i12}, \ldots, S_2^{i1n}$, and sorts $S_2^{i11}, S_2^{i12}, \ldots, S_2^{i1n}$ in the order of $s_{11}, s_{12}, \ldots, s_{1h_1}, s_{21}, s_{22}, \ldots, s_{2h_2}, \ldots, s_1, s_2, \ldots, s_b$, generates a process-based supplemented machining sequence $S_2^{i11'}, S_2^{i12'}, \ldots, S_2^{i1n'}$. Finally, add the target cell group S_2^{i12} to complete the process-based cutter-layer sorting.

<u>Sequencing of the machining cell based on the simulated annealing algorithm:</u>

After the machining cell grouping and the sorting based on the technology process, the first to third level cell groups are all sorted on the process level. As the processing order of the machining cells in the fourth-level group has little correlation with the process, to reduce the useless path between machining cells, a simulated annealing algorithm is used to optimize the geometrical paths between machining cells.

The optimization model of the path between machining cells is defined as follows: (1) The unit path is defined as the tool path segment for the machining cell and its start and end points. (2) The representation is the path between the machining cells and its solution space. (3) The solution target is the path optimization target. (4) The evaluation function, divided into closed-loop and open-loop, is used to evaluate the solution result. (5) The acceptance function is a function established according to the Metropolis probability acceptance criterion, used to decide whether to accept the new solution.

The simulated annealing algorithm flow is as follows:

Step1. Define and initialize the cooling progress parameters, the number of times s that the solution in the Mapkob chain length has no change, and the initial solution q_0;

Step2. Repeat Step3 to Step5 for the current annealing temperature tk and the number of iterations i=1, 2, ⋯, L_k;

Step3. Transform the initial solution q_i of the current iteration to randomly generate its new solution;

Step4. Calculate the function cost difference $\Delta eval_i$;

Step5. Determine whether to accept the new solution according to the acceptance function, if accepted, set $q_{i+1}=q_i^{'}$, otherwise $q_{i+1}=q_i$;

Step6. After L_k iterations, perform annealing to cool down;

Step7. If the iteration termination condition is met, output the current optimal solution and end the program. Otherwise, return to Step2 and continue the iterative calculation. When there is no change in the solution in the length of several adjacent Mapkob chains, the iteration is exited.

Conclusions:

In this study, a process-based optimization sequencing method of machining cells is proposed. This method comprehensively considers the macro-process flow and the sorting in the working steps, and effectively integrates the sequencing of the process level and the geometric level. It is mainly divided into macro level (process level) and micro level (cutter level). The sequencing results meet the process requirements, which can effectively reduce interference and over-cutting in the machining process, with short machining path and high efficiency.

References:

[1] Bi, Z.-M.; Wang, L.-H.: Optimization of machining processes from the perspective of energy consumption: A case study, Journal of Manufacturing Systems, 31(4), 2012, 420-428. https://doi.org/10.1016/j.jmsy.2012.07.002

[2] Huang, B.; Zhang, S.-S.; Huang, R.; Li, X.-L.; Zhang, Y.-J.; Liang, J.-C.: An Effective Numerical Control Machining Process Optimization Approach of Part With Complex Pockets for Numerical Control Process Reuse, IEEE Access, 7, 2019, 45146-45165.https://doi.org/10.1109/ACCESS.2019.2908877

[3] Xu, J.-L.; Zheng, G.-L.; Du, B.-R.; Chu, H.-Z.; Wu, F.-M.: Mathematical model and algorithm of toolpath optimization on aircraft structural parts, International Journal of Production Research, 52(4), 2014, 1142-1149. https://doi.org/10.1080/00207543.2013.842022

[4] Zhang, C.-W.; Han F.-Y.; Zhang W.: A cutting sequence optimization method based on tabu search algorithm for complex parts machining, Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 233(3), 2019, 745-755.https://doi.org/10.1177/0954405417752527

[5] Zheng Z.-J.; Wang, Q.-S.; Zheng, G.-L.; Zhu, J.-B.: An optimal approach to manufacturing planning for complex prismatic parts with interacting feature, The International Journal of Advanced Manufacturing Technology, 94(1), 2018, 585-597.https://doi.org/10.1007/s00170-017-0865-1