Chapter 2
Different Phases of Setup Planning

Abstract In this chapter different phases of setup planning task are discussed in detail. Setup planning mainly comprises of feature grouping, setup formation, datum selection, machining operation sequencing, and setup sequencing. The main criteria for feature grouping and setup formation are tool approach direction and tolerance relation among the features. Datum selection primarily depends on area of a feature, its orientation, surface quality and its tolerance relations with other features. Machining operation sequencing and setup sequencing is done based on feature precedence relations.

Keywords Features · Datum · Setups · Feature precedence relation · Operation sequencing

2.1 Introduction

Setup planning is an important intermediate phase of process planning. Output of a setup planning system gives the necessary instructions for setting up parts for machining. Setup planning consists of various phases such as feature grouping, setup formation, datum selection, machining operation sequencing, and setup sequencing. It takes information on features of a part, machining operations, machine tools and cutting tools as inputs from part representation database and manufacturing resource database. The part representation database comprises the information of the part including features of the part, part dimensions, shape, tolerances, surface finish, etc. Similarly, manufacturing resource database comprises information of machining operations, machine tools, cutting tools, materials, etc. Based on these inputs, manufacturing knowledge, and constraints in setup planning (discussed in Sect. 1.4), setup planning is performed. Different phases of setup planning are discussed in detail in the following sections.

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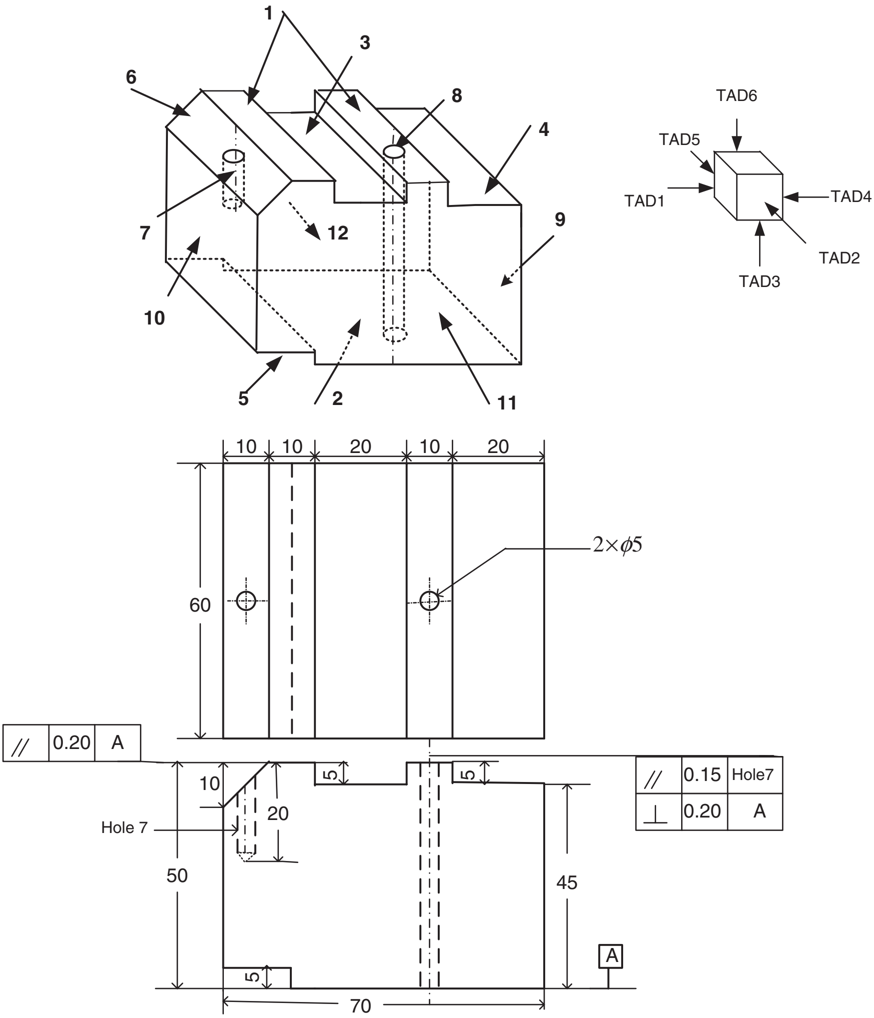
2.2 Feature Grouping

A part to be machined contains a number of machining features. The machining features represent the geometry of a part. A raw stock is converted to a finished part after machining these features on it. A group of features are machined in a setup without repositioning the part. Features to be machined in a particular setup are grouped together and machined in a particular machining sequence. Machining of the maximum number of features in the same setup ensures better tolerance achievement. The different features of the part are assigned to different setups based on several criteria such as tool approach direction (TAD) of the feature, tolerance requirements, precedence relations among the features, feature geometry, and feature interactions. Clustering of features and their machining operations into different groups is primarily done based on their TADs. For each feature to be machined, the TAD is to be identified first. A prismatic part can have six TADs and a rotational part can have two TADs as shown in Figs. 1.7 and 1.8 respectively. A feature may have a single TAD or multiple TADs. Another important criterion for feature grouping is tolerance relations among features. Normally, features with tight tolerance relations are assigned to the same setup. The following methodology is adopted for grouping of features for setup formation.

- Features with a common single TAD are grouped together to form a common TAD feature cluster. A common TAD feature cluster can be machined in the same setup.
- A feature having multiple TADs can be assigned to different TAD feature clusters and thus alternative machining sequences can be obtained for the same component. Alternatively, it can be assigned a single TAD based on its tolerance relations with other features. For example, if a multiple TAD feature (say *a*) has tolerance relation with only one feature (say *b*) having a single TAD common with *a*, then the feature *a* is assigned the TAD of *b*.
- If a multiple TAD feature (say *a*) has tolerance relation with more than one feature (say *b* and *c*) each having a single TAD, then the feature *a* is assigned the TAD of *b* or *c*, depending on whichever has tighter tolerance relationship with *a*.
- If a multiple TAD feature has no tolerance relationship with other features, it is assigned the TAD of a feature cluster where there are the maximum numbers of features. Machining of the maximum number of features in the same setup with the same datum will ensure better tolerance achievement and reduced machining time and cost.

To explain the method described above, the following example is taken. Figure 2.1 shows a component to be machined along with the detailed information on its features, dimensions, machining operations needed, TAD and tolerances among the features.

In Fig. 2.1, all the six faces (faces 1, 2, 9, 10, 11, and 12) of the prismatic block are initially rough machined and only faces 1 and 2 are considered as machining features. The through hole 8 has parallelism tolerance 0.15 mm with the blind hole 7



Feature	Name	Operation	TAD
1	Face	101 Milling	TAD1,TAD2,TAD4,TAD5,TAD6
2	Face	102 Milling	TAD1,TAD2,TAD3,TAD4,TAD5
3	Slot	201 Milling	TAD2, TAD5, TAD6
4	Step	501 Milling	TAD2, TAD4, TAD5, TAD6
5	Step	502 Milling	TAD1, TAD2, TAD3, TAD5
6	Chamfer	400 Chamfering	TAD1, TAD6
7	Blind hole	301 Drilling	TAD6
8	Through hole	302 Drilling	TAD3, TAD6

Fig. 2.1 A component with its features

and perpendicularity tolerance 0.20 mm with face 2, so it has a tighter tolerance relation with 7. Face 1 has parallelism tolerance 0.20 mm with face 2. Face 2 also has positional tolerance relations with features 4, 5, and 6. Through hole 8 has two TADs and it can be assigned TAD6 based on its tighter tolerance relation with feature 7. Features 1, 3, 4 and 6 have multiple TADs and they can be assigned to TAD6 feature cluster where there is the maximum number of features which will ensure better tolerance achievement and reduced machining time and cost. Similarly features 2 and 5 are assigned to TAD3 feature cluster. Thus, all the features can be incorporated into two different TAD feature clusters, viz. TAD6 and TAD3 feature cluster.

2.3 Setup Formation

After grouping of features based on TAD and tolerance relations, setups are formed. In each setup, a number of features are to be machined. For setup formation, different common TAD feature clusters are grouped together considering the machine capability. Total number of setups depends on the machine capability in respect of feature access direction for machining. For a conventional milling or drilling machine, there can be maximum six setups for machining prismatic parts considering their six TADs. Nowadays, various milling as well as drilling operations can be performed in a modern machining center (MC) equipped with rotary index table and automatic tool changer (ATC). Most of the machining centers contain simultaneously controlled three Cartesian axes X, Y, and Z. It is possible to machine five faces of a cubic component in these machines in a single setup. The five common TAD feature clusters (TAD1, TAD2, TAD4, TAD5 and TAD6 as shown in Fig. 1.7) can be grouped into one setup and the remaining common TAD feature cluster TAD3 can be assigned to the other setup. The component can be machined using only two setups compared to six setups of conventional machines.

For rotational parts, features and their machining operations for a given machine tool are clustered into two groups or two setups: (i) machining operations to be performed from the right and (ii) machining operations to be performed from the left. The proper decision is to be taken after considering the TADs and relative tolerance relationships among the features. Note that only two setups—setup-left and setup-right are possible for machining of rotational parts. For example, for the rotational part shown in Fig. 1.8b, features 1, 2, 3, and 4 can be assigned to setup-left and 5, 6, and 7 can be assigned to setup-right.

2.4 Datum Selection

In setup planning, selection of proper datum is essential for attaining the specified tolerances of the machined component. For creating reference for a component to be machined, datum is used. Once the features to be machined are grouped and setups are formed, datum for each setup is to be selected. Setup datum provides a definite and fixed position for machining the component. Datum planes and datum features are discussed in Sect. 1.2.4. Generally datum features rest on datum planes. The imaginary plane on which a component lies during machining is called the primary datum plane. The actual feature of the component that lies on the primary datum plane is called the primary datum. For prismatic components, primary datum is normally a face of the component, resting on which the features in a setup undergo machining. However, a datum feature may be a face, an axis, a curve or a point. In case of rotational components, both holes and surfaces can be used as datum features. Datum selection is the task of identifying the potential features which can serve as primary, secondary and tertiary datum for each setup. Features sharing common TAD and datum are naturally grouped into one setup.

Selection of the proper datum is one of the most challenging tasks in setup planning [8]. The approaches found in the literature for selection of datum are diversified in terms of criteria considered, such as total area of a face, its orientation, tolerance relation with other features, stability it provides, and symmetry and intricacy of a face. Large and maximum area face has been the most widely used criterion for selecting the primary datum for machining [3, 14]. However, surface area is not the only consideration for selecting datum. For proper location, the surface quality of datum is also important. It is well recognized that surface finish is one of the criteria for assessing the suitability of a face to be selected as datum [2, 9, 13, 15, 18]. Usually, the datum surfaces are the machined surfaces. However, it is to be noted that Hazarika et al. [8] observed that under some circumstances, excessively smooth surface as datum may produce more manufacturing errors compared to a rough surface datum. Many researchers consider tolerance relations among features as the prime criteria for selecting datum [1, 6, 7, 11, 17]. Selection of proper datum is very important for tolerance requirements and functionality of the part. To select datum for a setup in case of a prismatic part, first all the faces of the part are identified. The faces having an orientation different from the faces being machined in that setup are sorted out. Then, they are assessed for suitability as datum based on the above mentioned criteria.

In case of rotational parts, the surface which has an orientation different from the surfaces being machined (for rotational parts, two orientations: orientation from the left and that from the right is possible) is selected as datum. Normally vertical surfaces are selected as locating datum and cylindrical faces are selected for clamping. Tolerance relations of the candidate datum feature with the machined surfaces in a setup are given importance. If no tolerance relationship exists between the surfaces, the surface with the largest diameter or the longest cylindrical surface having an orientation different from the surfaces being machined is selected as datum. Generally the two faces perpendicular to the axis of the part are selected as locating datum. In Fig. 2.2, for machining the features 5, 6 and 7 which have TAD right, the vertical face of feature 4 (which has the largest diameter) is selected as locating datum and the cylindrical face of feature 4 is used for clamping. The priorities used for selection of primary datum are as follows:

Priority 1: The face having the maximum number of tolerance relations with other features should be selected as primary datum. Huang and Liu [10] suggested several setup methods for attaining critical tolerance relationship between two features of a part. One of them is to use one feature as datum for machining the other

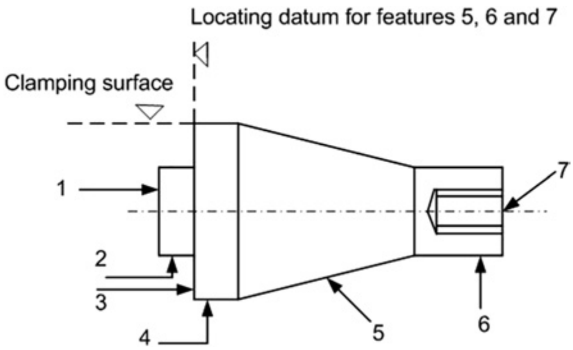


Fig. 2.2 Datum for a rotational part

feature for attaining better tolerance relationship. For example, in Fig. 2.1, face 2 has the maximum number of tolerance relations with other features. It has parallelism tolerance with feature 1, perpendicularity tolerance with feature 8, and positional tolerances with features 4, 5, and 6. Therefore, face 2 is selected as primary datum for machining the features 1, 3, 4, 6, 7, and 8 in one setup.

Priority 2: Another priority for selecting primary datum is surface area of a face. The largest surface area face is normally selected as primary datum as it provides better stability during machining. However the selection is affected by orientation of the face, TAD of the features in the setup, etc. All the candidate faces for primary datum can be evaluated for surface area and the maximum area face can be selected.

Priority 3: Machined faces are selected as primary datum. The surface quality of datum is an important factor as it locates a component to be machined. Therefore, surface finish is one of the criteria for assessing the suitability of a face to be selected as datum.

For selecting secondary datum, all the faces perpendicular to the primary datum are considered and the largest face is selected as the secondary datum. Similarly, the tertiary datum is the largest face which is perpendicular to both primary and secondary datum.

2.5 Machining Operation Sequencing Within a Setup

In each setup, a number of features to be machined are grouped together. The appropriate machining operations to produce each feature are to be selected and sequenced in a proper and feasible manner. For example, drilling operation can be selected to produce a hole feature, milling operation can be selected to produce a step feature and so on. It may be necessary to consult the appropriate vendor catalogues of the manufacturing equipment present in the shop floor and manufacturing process handbooks for detailed information about process capabilities of various machining operations. These catalogues and handbooks provide the dimensions, tolerances and the surface finish ranges attainable by different machining processes. Sequencing these machining operations within each setup is the most challenging task in setup planning. Machining operations sequencing has the greatest impact on machined part accuracies. The decision making in sequencing machining operations depends on certain constraints, viz. precedence constraints, different machining constraints and good manufacturing practice. For example, machining of external surfaces is followed by machining of internal surfaces and rough machining is followed by semi-finish machining and then finish machining and so on. Similarly, boring (or reaming) must be performed after drilling, drilling must be performed before tapping threads in a hole. Grinding is usually the final operation to be performed in order to obtain the precision required of the feature. For external features, turning, taper turning and grooving are normally performed before grinding and so on.

One important criterion for machining operation sequencing is to minimize tool changes. By grouping the similar machining operations together, (for example, grouping all the drilling operations together) it is possible to reduce the number of tool changes and idle tool motion. The necessary knowledge for sequencing machining operations is based on heuristic and expert knowledge from various sources such as handbooks, textbooks and interviews with experts and skilled machinists. Some knowledge is gathered from observations of actual machining in the shop floor. Researchers have tried to generate feasible machining sequences using different approaches such as expert systems, fuzzy logic, neural networks, PSO techniques, etc. based on criteria of minimum number of setups and tool changes and non-violation of feature precedence relations [3–7, 12, 16].

2.5.1 Generation of Machining Precedence Constraints

During machining of the features comprising a part, certain precedence relations among the features are to be respected. These precedence relations arise due to basic manufacturing principles and feature interactions. A precedence relation between two features F1 and F2, denoted as F1 $\rightarrow$ F2, implies that F2 cannot be machined until the machining of F1 is complete. Different precedence relations are obtained due to area/volume feature interactions, tolerance relations, feature accessibility, tool interaction, fixturing interaction, datum/reference/locating requirements, and constraint of good manufacturing practice. Some examples of precedence constraints are as follows: if there is a feature *a* of name hole which is to be drilled on a chamfered face *b*, then due to tool interaction constraint, the drilling of hole *a* is to be done prior to the chamfer *b*, or if there is an internal feature *a* which is nested in another feature *b*, then due to parent-child precedence constraint, the machining of feature *b* is to be done prior to the machining of *a*. Similarly, if a feature *a* is the datum/reference for feature *b*, then *a* has to machined prior to *b* which will result in datum/reference precedence constraint. Figure 2.3 shows some of the precedence relations collected from the literature.

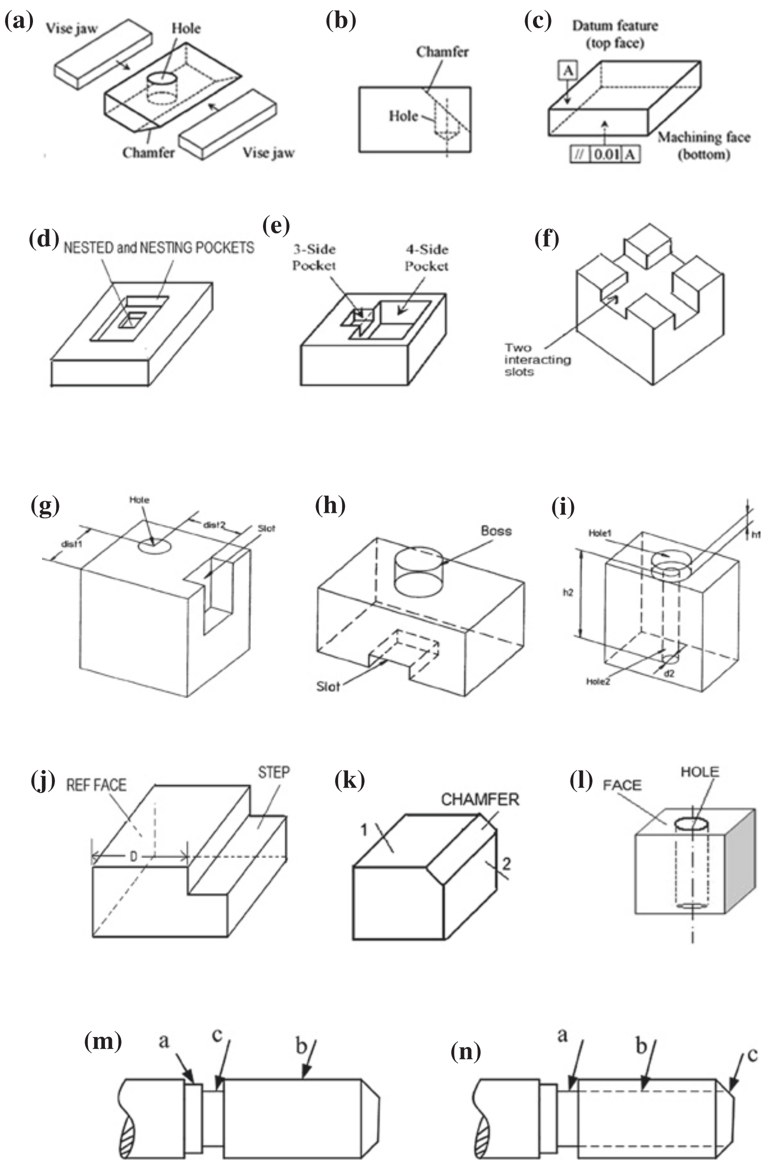


Fig. 2.3 Different precedence relations collected from the literature. Reproduced with kind permissions: **a**–**e** from Liu and Wang [16], Copyright [2007] Elsevier, part of **f** from Pal et al. [19], Copyright [2005] Elsevier and **g**–**i** from Zhang et al. [20], Copyright [1995] Springer Science and Business Media. **a** Drill hole → Chamfer. **b** Drill hole → Chamfer. **c** Datum A → Bottom face. **d** Nesting pocket → Nested pocket. **e** Base 4-side pocket → 3-side pocket. **f** Slot1 → Slot2 or Slot2 → Slot1. **g** Slot → Drill hole. **h** Slot → Boss. **i** Hole1 → Hole2. **j** Ref face → Step. **k** Faces 1 and 2 → Chamfer. **l** Face → Drill hole. **m** a → c, b → c. **n** a → b, c → b

Figure 2.3a depicts a precedence constraint arising due to fixturing interaction. Drilling the hole should precede the chamfer as fixturing will be difficult for drilling after chamfering. There will be less contact area for clamping the vise jaw if chamfering is done first. For similar reason, the slot precedes the boss in Fig. 2.3h. An accessibility/tool interaction constraint is shown in Fig. 2.3b where positioning the drilling tool will be difficult if chamfering is done first. Same is the case in Fig. 2.3m, where machining of the groove *c* between two adjacent external cylindrical surfaces *a* and *b* is done after machining of *a* and *b*. Figure 2.3c depicts the precedence constraint arising due to tolerance relation with the datum feature. The bottom face has tolerance relation with the datum face A and face A is to be machined first. Figure 2.3d shows two nested pockets having volumetric interaction, i.e. common volume to be removed. The smaller pocket is nested in the bigger pocket and the machining of the bigger/nesting pocket precedes the smaller/nested pocket. This type of precedence relation is called parent–child relation. The parent/nesting feature is to be machined prior to the child/nested feature. In Fig. 2.3e, the two pockets have only area interaction in the form of a common face. The 4-side base pocket is opening up to another 3-side pocket and the convention is to machine the base feature first. Figure 2.3f is a case of no precedence; any of the two slots can be machined first. Figure 2.3g, j shows the precedence of machining the reference features first. In (g), the hole is referenced with respect to the slot and in (j), the step is referenced with respect to the vertical face and reference features are to be machined first. Figure 2.3i shows good manufacturing practice of drilling the smaller depth hole prior to higher depth hole. Figure 2.3k, l shows the precedence of machining the adjacent faces first and then chamfering/drilling. There are certain constraints requiring that the subsequent features should not destroy the properties of features machined previously. An example is that the machining of a chamfer and a groove must be completed prior to that of the adjacent thread as shown in Fig. 2.3n.

These feature precedence relations are derived from manufacturing practice and there may be uncertainty about the validity of some assumed relations. The optimal machining sequence depends to a large extent on precedence relations. The validity of the precedence relations are to be reviewed keeping in mind the other related factors such as machining cost and time, work material properties, the required surface finish, machining passes (single or multi), etc.

First, a sequence of machining operations is created within a setup based on their precedence relations. This operation sequence can be modified by grouping operations of same tool together as long as the precedence relations are respected. Moreover, for machining operation sequencing within a setup, the information on preceding operation for each machining operation is required. For example, the preceding operation for machining a nested feature is machining of the nesting feature which is again preceded by machining of its reference feature. These information/facts are created by the generation of precedence relations. An operation may have multiple preceding operations. A machining operation is assigned to a setup only if all its preceding operations have been assigned. Thus, using the precedence constraint information, a feasible sequence of machining operations within each setup is generated. The machining operations are arranged in the sequential order in which they are to be performed.

2.5.2 Good Manufacturing Practice

Machining operations sequencing also depends on some rules of thumb evolving from decades of experience which are practised in the industry. These are considered as good manufacturing practice. For example, in case of drilling of two concentric holes, a hole of smaller diameter is drilled prior to a hole of larger diameter. Similarly, the hole of longer depth is drilled prior to the hole of shorter depth if they are concentric. However, some precedence relation may have an element of uncertainty. In the above mentioned examples of drilling concentric holes, the decision depends on many related factors like hole dimensions, ease of access, tool used, possibility of tool damage, material properties, cutting parameters, etc. Therefore, validity of the precedence relations are to be reviewed keeping in mind the other related factors.

2.6 Setup Sequencing

After the features and their machining operations within a setup are sequenced, the setups are also to be sequenced in a similar manner. Precedence relations described above are very important and prime criterion for setup sequencing. Moreover, for sequencing the setups, effect of machining of the features in the preceding setups on their successive setups are to be considered. A setup where greater numbers of features are present should not be considered first for machining. It may give rise to problems of instability and insufficient locating and clamping surface area for the remaining setups. For the same reasons, it is preferred that smaller sized features should be machined prior to larger sized features. Considering these constraints, the following principles can be followed for sequencing different setups for machining a component:

- Setups are sequenced depending on the precedence relations existing among the features present in different setups.
- The setup with the maximum number of features is preferably machined last provided precedence relations among the features are respected.
- Feature dimensions are to be taken into account and larger sized features are preferably machined last as they affect the stability, locating and clamping in subsequent setups.

2.7 Conclusion

In this chapter the different phases of setup planning are presented in detail. Feature grouping, setup formation, datum selection, machining operation sequencing and setup sequencing functions are discussed with relevant examples. Feature precedence relations arising due to various machining conditions are explained with examples. The role of feature precedence relations in machining operation sequencing and setup sequencing is highlighted.

References

1. Bansal S, Nagarajan S, Reddy NV (2008) An integrated fixture planning system for minimum tolerances. Int J Adv Manuf Technol 38:501–513
2. Deiab IM, Elbestawi MA (2005) Experimental determination of the friction coefficient on the workpiece-fixture contact surface in workholding applications. Int J Mach Tools Manuf 45:705–712
3. Gologlu C (2004) A constraint based operation sequencing for a knowledge based process planning. J Intell Manuf 15:463–470
4. Gu P, Zhang Y (1993) Operation sequencing in an automated process planning system. J Intell Manuf 4:219–232
5. Gu Z, Zhang YF, Nee AYC (1997) Identification of important features for machining operations sequence generation. Int J Prod Res 35:2285–2307
6. Guo YW, Li WD, Mileham AR, Owen GW (2009) Application of particle swarm optimization in integrated process planning and scheduling. Robot Comput Integr Manuf 25:280–288
7. Guo YW, Mileham AR, Owen GW, Maropoulos PG, Li WD (2009) Operation sequencing optimization for five-axis prismatic parts using a particle swarm optimization approach. Proc ImechE Part B J Eng Manuf 223:485–497
8. Hazarika M, Dixit US, Deb S (2010) Effect of datum surface roughness on parallelism and perpendicularity tolerances in milling of prismatic parts. Proc ImechE Part B J Eng Manuf 224:1377–1388
9. Hebbal SS, Mehta NK (2008) Setup planning for machining the features of prismatic parts. Int J Prod Res 46:3241–3257
10. Huang SH, Liu Q (2003) Rigorous application of tolerance analysis in setup planning. Int J Adv Manuf Technol 3:196–207
11. Huang SH, Xu N (2003) Automatic set-up planning for metal cutting: an integrated methodology. Int J Prod Res 41:4339–4356
12. Kim IH, Suh H (1998) Optimal operation grouping and sequencing technique for multistage machining systems. Int J Prod Res 36:2061–2081
13. Kim IH, Oh JS, Cho KK (1996) Computer aided setup planning for machining processes. Comput Ind Eng 31:613–617
14. Kumar AS, Nee AYC, Prombanpong S (1992) Expert fixture-design system for an automated manufacturing environment. Comput Aided Des 24:316–326
15. Lee NKS, Chen JY, Joneja A (2001) Effects of surface roughness on multi-station mechanical alignment processes. ASME J Manuf Sci Eng 123:433–444
16. Liu Z, Wang L (2007) Sequencing of interacting prismatic machining features for process planning. Comput Ind 58:295–303
17. Mei J, Zhang HC, Oldham WJB (1995) A neural networks approach for datum selection. Comput Ind 27:53–64
18. Ong SK, Nee AYC (1998) A systematic approach for analyzing the fixturability of parts for machining. ASME J Manuf Sci and Eng 120:401–408
19. Pal P, Tigga AM, Kumar A (2005) A strategy for machining interacting features using spatial reasoning. Int J Mach Tools Manuf 45:269–278
20. Zhang YF, Nee AYC, Ong SK (1995) A hybrid approach for setup planning. Int J Adv Manuf Technol 10:183–190

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