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THE IDEA OF DATABASE
FOR RECORDING INTERMEDIATE STATES
OF ROTARY PARTS FOR CAPP USE

KONCEPCJA BAZY DANYCH
DO ZAPISU STANÓW POŚREDNICH PRZEDMIOTÓW
OBROTOWYCH DLA POTRZEB SYSTEMÓW CAPP

Abstract

The paper presents a developed database for recording intermediate states of a workpiece. This solution can be used for automation of the calculation process, intermediate states and blank design generation for wide sets of parts. The calculation formulas, decision parameters and definition of intermediate states are also presented in this paper. The results from the developed SQL queries are attached. The presented idea and implemented database will reduce the time of design of a blank for *rotary and axisymmetric parts* in machining processes.

Keywords: CAPP, intermediate states of features

Streszczenie

W artykule przedstawiono bazę danych opracowaną do zapisu stanów pośrednich przedmiotu obrabianego. Prezentowane rozwiązanie pozwala na automatyzację procesu obliczeniowego oraz generowanie stanów pośrednich i półfabrykatu dla szerokiego zbioru części. Stosowne wzory, parametry decyzyjne, definicja stanów pośrednich również zostały przedstawione. Dołączono również przykładowe rezultaty działania opracowanych kwerend SQL. Prezentowany pomysł i zaimplementowana baza danych pozwolą na znaczne skrócenie czasu projektowania półfabrykatów dla przedmiotów obrotowych osiowosymetrycznych, stosowanych w obróbce skrawaniem.

Słowa kluczowe: CAPP, stany pośrednie cech technologicznych

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1. Introduction

The Computer Aided Process Planning (CAPP) systems are still a promising solution. Other CAx systems, like CAD (Computer Aided Design) or CAM (Computer Aided Manufacturing) are very popular on the market. CAD systems offer e.g. parametric 3D design and facilities to create 2D drawings. CAM systems mostly support the cutting machinetool NC code generation. There are also available integrated CAD/CAM solutions, like Dassault Systemes CATIA. But there is a gap between these systems. The engineers have to create 3D models of a product and then they can use it to create a machining process in CAM. Unfortunately, they need to be a specialist in machining process planning. They have to predict which machinetools will be used, what equipment is necessary, what tools can be applied, how to calculate machining parameters and other similar features. This task could be aided by CAPP systems.

The idea of a CAPP system is not new. The first research studies were published more than 30 years ago. A good example of the CAPP theory can be found in [1]. Chang, in his book [1], defines possible scenarios to create a CAPP system using different techniques. The CAPP system implementation depends on the selected method. The following methods can be distinguished [1]: variant, generative and semi-generative.

The CAPP system is a tool used to create the process plan. It could aim at different manufacturing methods, but a typical application is to aim at machining process planning [3, 5]. In that case, input information is a workpiece data. This data can be entered into the CAPP system manually or can be retrieved from the CAD system (based on e.g. feature recognition procedures) [4, 5]. The machining process plan, recorded and presented in different forms, is an output from CAPP.

2. The intermediate states in the machining process

The manufacturing process can be, in general, described as follows. The given *part*, which has to be machined from a selected (or designed) *blank* (semi-finished product or raw material), is passing through successive stages of that process. As a result, the *ready part* (final product), which fulfills quality requirements, is processed. The *workpiece*, passing through the process, is changing its *state* (see Fig. 1), which is referred to as *intermediate state of workpiece features* S_f where f is an index of an intermediate state and $f = 0 \dots F$, where F is the highest number of recorded S_f . There are two special states: *initial state* S_0 , given by a blank design and *final state* S_F , given by a ready part drawing.

The intermediate states are necessary to create operational drawings, but the creation method depends on their part class (from a technological point of view). To simplify further his considerations, the author made an assumption to consider only *rotary and axisymmetric parts*. This class contains parts like shafts, axles, screws, sleeves, disks etc. It is a very wide class of parts used in mechanical design.

To create a machining process plan, the design of a blank is necessary. The type, geometry, quality of the designed blank has a big influence on the machining process's structure, number of operations, time and cost. That means, the selection and design of a blank is a very significant stage. If the design of a blank is known, then the machining process can be planned.

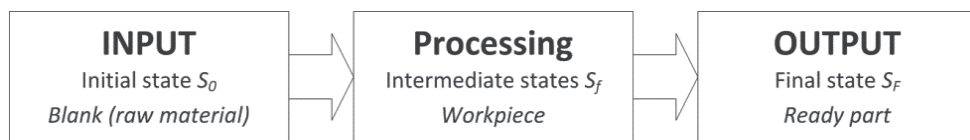


Fig. 1. General model of manufacturing process and intermediate states of workpiece

The design of a blank can be created using a reverse method. By prediction of previous stages, the following intermediate states can be created. Starting from the ready part drawing, the stages like: before finishing (BFN), before medium turning (BMT) and before roughing (BRG) can be calculated. To do this proper values of operational allowances should be applied. Below the process of blank design creation will be presented with intermediate states recording, based on a samplshaft, presented in Fig. 2.

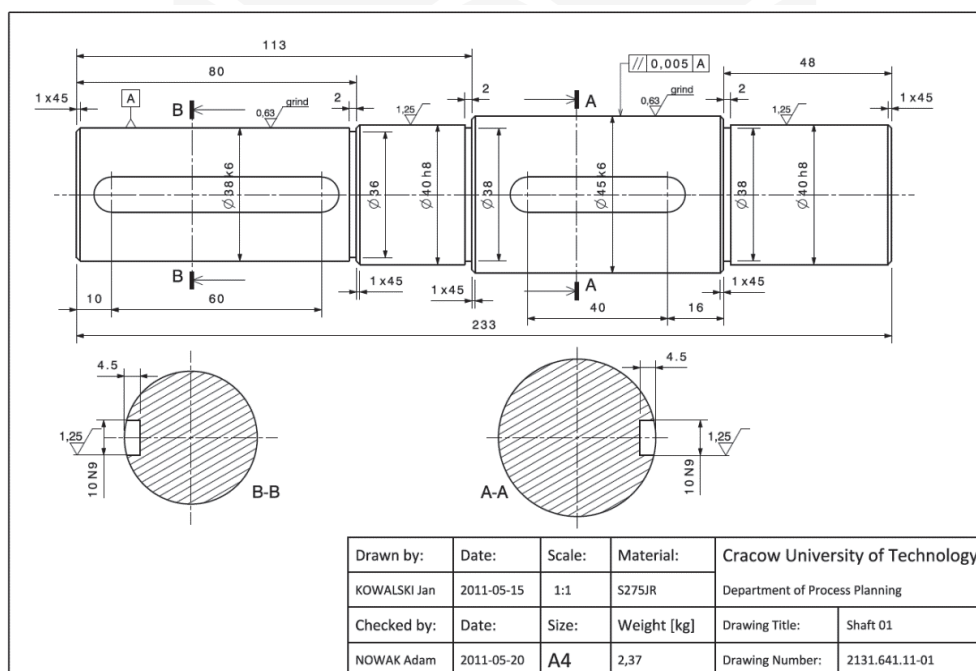


Fig. 2. The example shaft No. 01

The main goal is to design a blank. To do this, it is necessary to find out:

- How to fix the part? It has influence on the predicted cutting allowances.
- How much material will be removed in the form of chips? From the economical point of view, it can be a decisive factor in the blank type selection.

- How many operations have to be applied for each feature (e.g. cylindrical surface)? It has influence on the number of operational allowances.
- The value of operational allowances. It has an influence on the blank's dimensions.

The first decision factor can be C_{SR} , slenderness of the shaft. It can be calculated using a simplified formula:

$$C_{SR} = \frac{L_T}{D_{\max}} \quad (1)$$

where:

- L_T – total length of the shaft,
- D_{\max} – diameter of the biggest cylindrical surface.

In case of shafts there are three main fixing possibilities:

- In 3-jaw chuck, which is recommended when $C_{SR} < 3$,
- Between centers (or in 3-jaw chuck and supported by live center) is recommended when: $3 < C_{SR} < 12$,
- Between centers with a steady roll it is recommended when: $C_{SR} > 12$.

To evaluate how much material will be removed in the form of chips we need to calculate the volume of workpiece V_{WP} and the volume of the cylinder envelope of workpiece V_{CE} . It could be calculated using the following formulas:

$$V_{WP} = \sum_{s=1}^n V_s = \sum_{s=1}^n \frac{\pi \cdot l_s \cdot d_s^2}{4} \quad (2)$$

$$V_{CE} = \frac{\pi \cdot L_T \cdot D_{\max}^2}{4} \quad (3)$$

where:

- s – number of step in the analyzed shaft, n is a total number of steps,
- l_s – length of step of the shaft (cylindrical surface),
- d_s – diameter of step of the shaft,
- V_s – volume of step of the shaft [dm³].

Then it is possible to calculate the mass using the following formula:

$$m = \rho \cdot V \quad (4)$$

When volume V [dm³] is calculated, mass m [kg] results from (4) if material density ρ is given. For most types of steel ρ is about 7.85 [kg/dm³].

The mass of the removed material m_{CP} in the form of chips can be expressed as:

$$m_{CP} = m_{CE} - m_{WP} \quad (5)$$

Finally, yield coefficient C_y [%], as an absolute rate measured by percentage of the removed material can be calculated from:

$$C_y = \frac{V_{CE} - V_{WP}}{V_{CE}} \cdot 100\% \quad (6)$$

The value C_y can be used for blank type selection. For example, if $C_y < 40\%$ we can select the hot-rolled bar, If $C_y > 40\%$ we should select the forging type. The limit value (like in this example 40%) should be calculated as a minimum cost balance between the blank's price and the manufacturing cost. This limit is very dependent on the volume of production.

To find out how many operations Q_{OP} should be applied for each feature, increase accuracy coefficient C_A can be used. It compares tolerances of applied blanks and each step of the shaft (defined in workshop drawing) [2]:

$$C_A = \frac{T_{BL}}{T_{Fi}} \quad (7)$$

where:

- T_{BL} – tolerance of the selected type of blank [μm],
- T_{Fi} – tolerance of a given feature (e.g. cylindrical surface) [μm].

Based on C_A the value can be decided:

- If $C_A < 10$ then one operation is sufficient, $Q_{OP} = 1$,
- If $10 < C_A < 50$ then two operations are necessary, $Q_{OP} = 2$,
- If $C_A > 50$ then three operations will be needed, $Q_{OP} = 3$.

The last stage is prediction of cutting allowances. There are a few methods, which can be applied, but the simplest one is to use allowance standards. For example, the IOS Kraków has worked out such standards [2]. The way of finding the right value of allowance is crucial. It is realized in a few steps. Firstly, the class of the part and its material should be recognized. Then the fixing way (workpiece setup), machining type and range should be defined. Finally, having regard to the above criteria, the right data table can be found. This data table contains values of allowances with division into workpiece sizes (length and diameter). It is needed to find out the total length L_T and average diameter D_{AVG} (note: this should be equivalent diameter, which gives the same value of the shaft's deflection like the original stepped shaft) of the part. To calculate this equivalent diameter, a simplified formula can be used:

$$D_{AVG} = \frac{A_{WP}}{L_T} = \frac{\sum_{s=1}^n A_s}{L_T} = \frac{\sum_{s=1}^n (l_s \cdot d_s)}{L_T} \quad (8)$$

where:

- A_{WP} – area of longitudinal cross-section of all workpieces [mm^2],
- A_s – area of longitudinal cross-section of a given step of the shaft [mm^2].

Using the presented above formulas, the following results for the sample shaft (see Fig. 1) can be presented for each step of the shaft (Table 1) and for the workpiece (Table 2).

Table 1

Parameters calculated for each step of Shaft 01

| s | l_s [mm] | d_s [mm] | A_s [mm ²] | V_s [dm ³] | m_s [kg] | IT | T_{BL} [μm] | T_{F1} [μm] | C_A | Q_{OP} |
|-----|---------------|---------------|-----------------------------|-----------------------------|---------------|------|------------------|------------------|-------|----------|
| 1 | 80 | 38 | 3040 | 0.0907 | 0.712 | k6 | 1600 | 16 | 100 | 3 |
| 2 | 33 | 40 | 1320 | 0.0415 | 0.326 | h8 | 1600 | 39 | 41 | 2 |
| 3 | 72 | 45 | 3240 | 0.1145 | 0.899 | k6 | 1600 | 16 | 100 | 3 |
| 4 | 48 | 40 | 1920 | 0.0603 | 0.474 | h8 | 1600 | 39 | 41 | 2 |

Table 2

Parameters calculated for workpiece Shaft 01

| L_F [mm] | D_{max} [mm] | C_{SR} | A_{WP} [mm ²] | D_{AVG} [mm] | V_{WP} [dm ³] | V_{CE} [dm ³] | C_Y [%] | m_{WP} [kg] | m_{CE} [kg] | m_{CP} [kg] |
|---------------|-------------------|----------|--------------------------------|-------------------|--------------------------------|--------------------------------|--------------|------------------|------------------|------------------|
| 233 | 45 | 5.1 | 9520 | 40.8 | 0.307 | 0.370 | 17.1 | 2.41 | 2.9 | 0.49 |

Table 3

The calculated intermediate states of Shaft01 (diameters before: BFN, BMT, BRG)

| s | l_s [mm] | d_s [mm] | Q_{OP} | d_{BFN} [mm] | d_{BMT} [mm] | d_{BRG} [mm] | d_{BL} [mm] |
|-----|---------------|---------------|----------|-------------------|-------------------|-------------------|------------------|
| 1 | 80 | 38 | 3 | 38.3 | 38.9 | 42.0 | 50 |
| 2 | 33 | 40 | 2 | 40.0 | 40.6 | 43.7 | 50 |
| 3 | 72 | 45 | 3 | 45.3 | 45.9 | 49.0 | 50 |
| 4 | 48 | 40 | 2 | 40.0 | 40.6 | 43.7 | 50 |

Moreover, for *Shaft01* the following allowances were selected:

- $Q_{RG} = 3.1$ [mm], allowance on a diameter for rough turning,
- $Q_{MT} = 0.6$ [mm], allowance on a diameter for medium turning,
- $Q_{FN} = 0.3$ [mm], allowance on a diameter for finishing (grinding).

Using these allowance values, the intermediate states of *Shaft01* were calculated. The results are presented in Table 3. Because the yield coefficient is only $C_Y = 17.1$ [%] and the maximum diameter (including necessary allowances) is $d_{BRG} = 49$, it was decided to choose a hot-rolled bar (a blank type) with $\varnothing 50$ (the bigger one, available on the market) and $T_{BL} = 1,6$ [mm].

3. The idea of a database for recording intermediate states

The most important question is about the process: Can it be automated? (see section 2 above). The answer is yes if the relational database is used.

To realize this idea it is necessary to record the geometry of the ready part, intermediate states and the blank. In the case of *rotary and axisymmetric parts*, the idea of 2.5D representation can be easily applied. Describing it very shortly: there is a closed contour (containing segments, arcs etc.) representing the upper-half of the cross section of the part, which can be rotated to get a 3D object. This method is used in 3D solid modelling and also in CAM to record workpiece geometry. Moreover, one important assumption was made. To simplify the calculation process, only the 1-st level of features will be considered. In case of rotary and axisymmetric parts, the 1-st level of features are machined first, for example their cylindrical (step of shaft), conical or spherical features. Then the 2-nd level features can be machined like: chamfer, rounding, undercut, keyway hole, metric thread etc.

Based on the idea presented above, the ERD diagram of relational database for recording intermediate states was developed and is presented in Fig. 3.

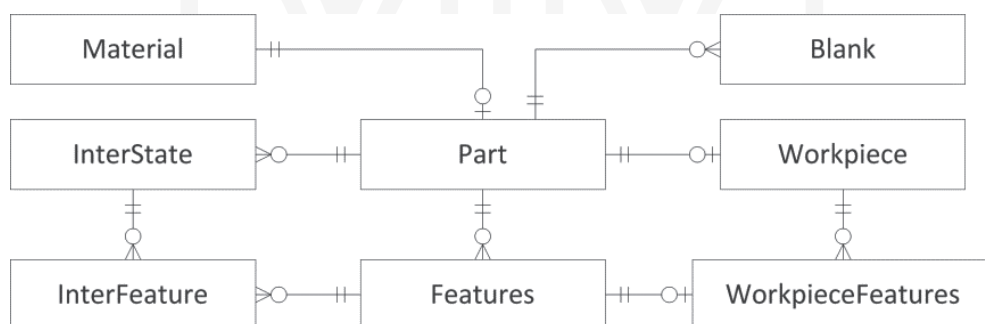


Fig. 3. The developed ERD diagram of relational database for recording intermediate states

To record a set of parts it is necessary to divide the data into two entities. The first table *Part* will contain a set of parts. The second table *Features* will contain the data describing each 1-st level feature of the part. The part can contain many features. Moreover, one material can be assigned to one part. The necessary calculations can be recorded in table *Workpiece* (data about the part) and in table *WorkpieceFeatures* (results for each feature). Using calculation results the intermediate states of a workpiece can be recorded (in table *InterState*) and intermediate states of all the features (in table *InterFeature*). The final result as a blank design can be recorded in table *Blank*.

Moreover, what is not presented on the ERD diagram, other necessary tables were added, which contain: the dimensions and tolerances of hot-rolled bars and forgings, the upper-lower deviations of fits, the cutting allowances for rough, medium and finish turning etc.

4. The implementation of the database and its testing

Based on the developed ERD diagram, the database in MS Access 2010 was created. It contains tables, a user interface (window forms), queries and modules written in the VBA language. For testing purposes, the data about more than 30 different parts was entered into the database. The source data is in tables: *Material*, *Part* and *Features*.

The core procedures was based on SQL queries. First decision parameters were calculated (see section 2). The SQL query, presented below, calculates parameters of each feature (as computed columns). The results, for the first shaft, are presented in Table 4.

```
SELECT IDP, FtNo, D, L, IT, Ra, L*D AS A, 3.14159*([L]/100)*
([D]/100)*([D]/100)/4 AS V, 7.85*V AS m FROM Features;
```

Table 4

The results from the SQL query: calculated parameters for each feature of two selected shafts

| IDP | FtNo | D | L | IT | Ra | A | V | m |
|---------|------|----|----|----|------|-------|------|------|
| Part001 | 1 | 38 | 80 | 6 | 0.63 | 3 040 | 0.09 | 0.71 |
| Part001 | 2 | 40 | 33 | 8 | 1.25 | 1 320 | 0.04 | 0.33 |
| Part001 | 3 | 45 | 72 | 6 | 0.63 | 3 240 | 0.11 | 0.90 |
| Part001 | 4 | 40 | 48 | 8 | 1.25 | 1 920 | 0.06 | 0.47 |

The next query calculates parameters for each workpiece (includes aggregated functions and computed columns). The results for the first five shafts are presented in Table 5.

```
SELECT IDP, SUM(L) AS LT, MAX(D) AS Dmax, SUM(A) AS AWP,
SUM(V) AS VWP, SUM(m) AS mWP, LT/Dmax AS CSR, AWP/LT AS DAVG,
3.14159*([Lc]/100)*([Dmax]/100)*([Dmax]/100)/4 AS VCE,
7.85*VWP AS mCE, mCE - mWP AS mCP, (VCE-VWP)/VCE AS CY
FROM WorkpieceFeatures GROUP BY IDP;
```

Table 5

The results from the SQL query: calculated parameters for each of the five selected shafts

| IDP | LT | Dmax | AWP | VWP | mWP | CSR | DAVG | VCE | mCE | mCP | CY |
|---------|-----|------|--------|-------|-------|-----|------|-------|-------|------|-------|
| Part001 | 233 | 45 | 9520 | 0,307 | 2,41 | 5,1 | 40,8 | 0,37 | 2,9 | 0,49 | 17,1% |
| Part002 | 430 | 95 | 36 325 | 2,427 | 19,05 | 4,5 | 84,4 | 3,047 | 23,92 | 4,86 | 20,3% |
| Part003 | 310 | 45 | 10 800 | 0,307 | 2,41 | 6,8 | 34,8 | 0,493 | 3,87 | 1,45 | 37,6% |
| Part004 | 315 | 75 | 16 693 | 0,729 | 5,73 | 4,2 | 52,9 | 1,391 | 10,92 | 5,19 | 47,6% |
| Part005 | 444 | 56 | 18 218 | 0,594 | 4,66 | 7,9 | 41 | 1,093 | 8,58 | 3,91 | 45,6% |

Next Table 6 presents the intermediate states of *shaft01* generated by the query, which combines the two tables (*InterState* & *InterFeature*). This example shows possibilities of using the developed database.

Table 6

The results from the SQL query: the intermediate states of shaft01 – final results

| IDISP | InterName | IDIFN | IFSType | L | D | Ra | IT |
|------------|-----------------------|--------|---------|------|------|------|----|
| Part001_FN | Before finishing | P1F1S1 | CYL | 80 | 38.3 | 1.25 | 9 |
| Part001_FN | Before finishing | P1F2S1 | CYL | 33 | 40 | 1.25 | 8 |
| Part001_FN | Before finishing | P1F3S1 | CYL | 72 | 45.3 | 1.25 | 9 |
| Part001_FN | Before finishing | P1F4S1 | CYL | 48 | 40 | 1.25 | 8 |
| Part001_MT | Before medium turning | P1F1S2 | CYL | 80 | 38.9 | 5 | 11 |
| Part001_MT | Before medium turning | P1F2S2 | CYL | 33 | 40.6 | 5 | 11 |
| Part001_MT | Before medium turning | P1F3S2 | CYL | 72 | 45.9 | 5 | 11 |
| Part001_MT | Before medium turning | P1F4S2 | CYL | 48 | 40.6 | 5 | 11 |
| Part001_RG | Before rough turning | P1F1S3 | CYL | 80 | 42 | 20 | 12 |
| Part001_RG | Before rough turning | P1F2S3 | CYL | 33 | 43.7 | 20 | 12 |
| Part001_RG | Before rough turning | P1F3S3 | CYL | 72 | 49 | 20 | 12 |
| Part001_RG | Before rough turning | P1F4S3 | CYL | 48 | 43.7 | 20 | 12 |
| Part001_BL | Hot-rolled bar | P1F1S4 | CYL | 3000 | 50 | 40 | 16 |

5. Conclusions

A lot of problems, in implementation of the CAPP system, are connected with workpiece data representation and automation of necessary calculations. The presented idea shows a simple solution of this problem. Thanks to the 2.5D representation of the workpiece (to record its features) and presented in section 2 formulas, it is possible to receive the necessary results automatically. It concerns intermediate states of the workpiece, which occur during machining in operations, and the final design of the blank.

This idea was used to build the database and was tested on more than 30 samples. All results confirm the correctness of the developed database. The next step of this work will be to use this module as a part of CAPP in a semi-generative method [3].

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