A knowledge base model of the computer-aided design system for solids of revolution press-forging

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Abstract. The main problem of creating computer-aided design systems (CAD) for press-forging processes is associated with a weak formalization of the subject area. An effective way for solving this problem is to provide the corresponding CAD with expert system properties when weakly structured knowledge is formalized in a certain way and transferred to the knowledge base. The paper describes the concept of developing a production knowledge base model of the computer-aided design system for solids of revolution press-forging. Some specific technological problems are examples of this model application in relation to tasks with point and interval solutions. The proposed concept of developing the knowledge base allows us to more formalize the subject area under consideration, to develop genetic algorithms for solving weakly structured problems of computer-aided forging process design, to ensure the work of appropriate programs without their adjustment to changing production conditions, and it can be used in other subject areas.

1. Introduction
The main problem of developing computer-aided press-forging design systems is associated with a weak formalization of design problems. It leads to the elaboration of approximate algorithms and programs for their solution. Therefore, in known CAD software [1-4], the solution of such tasks is often put on the shoulders of users by creating interaction mechanisms to correct the results of computer-aided design in the dialog mode. At the same time, CAD developers always strive to reduce the share of human participation in the computer-aided design process.

An effective way to solve this problem is to assign the corresponding CAD with expert system properties [5]. Thus, weakly structured knowledge is formalized and transferred to the knowledge base [6]. The knowledge base contains information about subject area regularities (principles, relationships, laws) in a certain form and allows one to set and solve problems in this area. Therefore, the knowledge base is a set of facts and heuristic rules of logical inference, which can be supplemented and refined during system operation without adjusting algorithms and programs.

This paper describes a model of the production knowledge base [6] of the computer-aided design system for solids of revolution press-forging accounting rules for solving weakly structured problems.

2. Knowledge base model
The common rule for solving weakly structured problems of computer-aided forging design based on the production knowledge base is presented as
and it is interpreted as follows: if events \( X_i = x_i, \ i = 1, 2, \ldots, k \) occur simultaneously (conditions are met), then an event \( Y = y \) occurs (it is the solution of the problem).

In the expression (1), \( X_i \) are independent factorial features (factors), affecting on the problem solution, \( k \) is the number of such factors, \( x_i \) are numerical or linguistic values of factors \( X_i \) that cause the event \( Y = y \) occurrence, \( Y \) is the effective feature, \( y \) is a numerical or linguistic value of the effective feature (the result of solving the problem).

In the subject area under consideration, events \( X_i = x_i \) are equivalent to events

\[
\left\{ \begin{array}{l}
\text{maxmin} \\
\text{maxmin}
\end{array} \right., \quad \in \text{maxmin} ;\quad \ldots;;, \quad 2,1,
\]

where \( \text{maxmin} \) and \( \text{maxmin} \) are technological intervals or finite sets from \( n \) possible values of factors (facts) leading to the solution \( Y = y \).

Factors \( X_i \) and facts \( \left\{ \begin{array}{l}
\text{maxmin} \\
\text{maxmin}
\end{array} \right., \quad \left\{ x_{i,1}; x_{i,2}; \ldots; x_{i,n} \right\} \) for each technological problem are set on the basis of modern knowledge about forging technology [7-10]. They entered the production knowledge base and refined without adjusting algorithms and programs both at the stage of configuring the system for the production conditions of specific enterprises and during its operation.

Similarly, the event \( Y = y \) in expression (1) is equivalent to events

\[
\left\{ \begin{array}{l}
\text{maxmin} \\
\text{maxmin}
\end{array} \right., \quad \in \text{maxmin} ;\quad \ldots;;, \quad 2,1
\]

where \( \left\{ y_{\text{min}}, y_{\text{max}} \right\} \) and \( \left\{ y_1 ; y_2 ; \ldots; y_m \right\} \) are intervals or finite sets from \( m \) possible result values \( Y \) corresponding to the events (2) that occurred, from which a single solution must be selected.

We will call the event \( Y \in \left\{ \begin{array}{l}
\text{maxmin} \\
\text{maxmin}
\end{array} \right., \quad \in \text{maxmin} ;\quad \ldots;;, \quad 2,1 \) an interval solution to the problem, and the event \( Y \in \left\{ y_{1} ; y_{2} ; \ldots; y_{m} \right\} \) is a point solution.

3. Examples of problems with interval and point solutions

An example of problems with an interval solution is the problem of calculating dimensions of intermediate blanks produced during forging. In this case, some functional dependence

\[
y = \phi(y_{\text{min}}, y_{\text{max}})
\]

is constructed that allows one to find a single solution from the interval \( \left\{ y_{\text{min}}, y_{\text{max}} \right\} \). In general, the problem of choosing a rational solution from a set of possible ones depends on the set goals and their relative significance and can be successfully solved by using the fuzzy set theory [7] and the theory of decision making in fuzzy conditions [8]. Examples of solving such problems for shaft press forging are considered in [9, 10]. In practice, the expression

\[
\phi(y_{\text{min}}, y_{\text{max}}) = \frac{y_{\text{min}} + y_{\text{max}}}{2}
\]

is often used as such a dependence so that the chosen solution meets all the conditions (2) with a guarantee.

Let us consider an example. The upset of a selected ingot is often used as an intermediate operation of press forging. As an example, we consider the problem of determining the diameter of the upset ingot for shaft forging (see figure 1).
Factors influencing on the problem solution are $X_1 = h_s / d_s$ and $X_2 = \left( d_s / d_{Pok} \right)^2$, where $h_s, d_s$ are the height and the diameter of the upset ingot; $d_{Pok}$ is the overall diameter of the forging. In metal forming, the factor $X_1$ is called the index of manufacturability for the upset ingot, the value of which is limited by $h_s / d_s \geq 0.6$. The factor $X_2$ is called the total forging ratio, which characterizes the degree of deformation during the entire forging process. It is usually taken $\left( d_s / d_{Pok} \right)^2 \geq 3$.

The result $Y$ of solving this problem is the value of the upset ingot diameter $d_s$ and the rule for obtaining the result can be, for example, presented as

$$X_1 = h_s / d_s \geq 0.6 \land X_2 = \left( d_s / d_{Pok} \right)^2 \geq 3 \Rightarrow Y = \frac{y_{\text{min}} + y_{\text{max}}}{2}.$$  

When you know the upset ingot volume, it is not difficult to calculate that the value of the effective feature $Y = d_s \in \left[ y_{\text{min}} = 2211, y_{\text{max}} = 2229 \right]$ and the solution of the problem is the value of $d_s = \frac{y_{\text{min}} + y_{\text{max}}}{2} = 2220$.

The knowledge base of the problem solution and the result of its solving are shown in table 1.

### Table 1. The knowledge base and the result of the problem solution.

| Factors and facts | Result |
|-------------------|--------|
| $X_1 = h_s / d_s$ | $X_2 = \left( d_s / d_{Pok} \right)^2$ |
| $y_{\text{min}}$ | $y_{\text{max}}$ |
| $x_1$ | $x_2$ |
| $d_{\text{min}}$ | $d_{\text{max}}$ |
| $s$ |
| $0.6$ | $3$ | $2211$ | $2229$ | $2220$ |

Users can clarify the facts of the knowledge base (the last row in table 1), changing the problem solutions without adjusting the algorithms and programs for solving.

An example of a problem with a point solution is the problem of determining the type of a forging. Press forging design is performed according to GOST 7062-90 [11], which considers five types of solids of revolution: $y_1 =$ SHAFT, $y_2 =$ PIPE, $y_3 =$ COUPLING, $y_4 =$ RING, $y_5 =$ DISK. The values of allowances, tolerances and forging overlaps for parts are determined by various tables of GOST 7062-90, depending on part types. In addition, the technological process of part production is strongly dependent on the forging type.

Factors, affecting on the solution of the problem of determining the forging type in accordance with [11], are the ratio of the determining dimensions

$$X_1 = \frac{L}{D} \quad \text{and} \quad X_2 = \frac{d}{D},$$

where $L$ is the overall length (height) of the forging, $D$ is the overall diameter, and $d$ is the diameter of the inner hole.

However, boundaries of determining dimension ratios proposed in [11], which are necessary to refer the forging to a specific type, are quite conditional. In several books [13, 14], as well as in technological instructions of enterprises, there are other boundaries of ratios, although slightly different from GOST 7062-90. And they also have successfully passed practical testing. Table 2 shows...
results of summarizing recommendations of such boundaries for three types of solids of revolution: COUPLING, RING, DISK.

| Forging type | Facts          |
|--------------|----------------|
|              | $x_1^{\min}$  | $x_1^{\max}$ | $x_2^{\min}$ | $x_2^{\max}$ |
| COUPLING     | 0.5            | 1.2           | 0             | 0.5           |
| RING         | 0.2            | 1.25          | 0.4           | 0.67          |
| DISK         | 0.2            | 0.8           | 0             | 0.5           |

It is easy to see that the boundaries of factor value intervals $x_1^{\min}, x_1^{\max}, x_2^{\min}, x_2^{\max}$ overlap and the rule (1–3) can lead to a state of uncertainty, in which it is necessary to make a reasonable decision. For example, a forging with $\frac{L}{D} = 0.7$ and $\frac{d}{D} = 0.45$ can be simultaneously attributed to COUPLING, RING or DISK.

The incorrectness of the facts from table 2 is due to the specificity of the subject area under consideration. In general case, it is simply impossible to determine the exact values of $x_1^{\min}, x_1^{\max}, x_2^{\min}, x_2^{\max}$. You must select the most likely choice from a set of COUPLING, RING, and DISK. Therefore, each possible solution $Y = y_j$ is assigned a conditional probability $p_j$ of its reliability

$$p_j = p(Y = y_j / \{X_i = x_i \in [x_i^{\min}, x_i^{\max}] \cup \{X_i = x_i \in \{x_{i,1}, x_{i,2}, ..., x_{i,n}\}\} \} i = 1, 2, ..., k)$$

and the solution of the problem is considered to be the choice $y_j$ that corresponds to the highest value of $p_j$. The calculation of conditional probabilities $p_j$, which are included in a production knowledge base, involves statistical analysis of the results of company's work for a certain period (e.g. calendar year) and the logical inference mechanism, which is well-known in expert systems. This mechanism is based on subjective probability and Bayes theorem [15]. In the future, statistical data is accumulated and processed automatically while the system is used.

4. Conclusion

The paper describes the concept of developing a production knowledge base model of the computer-aided design system for solids of revolution press-forging. Some specific technological problems are examples of this model application in relation to problems with point and interval solutions.

The proposed concept of developing a knowledge base allows one to increasingly formalize the subject area, to develop genetic algorithms for solving weakly structured problems of computer-aided press-forging design, to ensure the work of appropriate programs without their adjustment to changing production conditions, and can be used in other subject areas.

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**Blank production in mechanical engineering** 1 20–23

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