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Retraction

Retracted: Research and Analysis of Out-of-Tolerance Problem in Mold Processing Based on Intelligence

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This article has been retracted by Hindawi, as publisher, following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of systematic manipulation of the publication and peer-review process. We cannot, therefore, vouch for the reliability or integrity of this article.

Please note that this notice is intended solely to alert readers that the peer-review process of this article has been compromised.

Wiley and Hindawi regret that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] J. Wang, "Research and Analysis of Out-of-Tolerance Problem in Mold Processing Based on Intelligence," *Advances in Multimedia*, vol. 2022, Article ID 3035155, 11 pages, 2022.

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Research Article

Research and Analysis of Out-of-Tolerance Problem in Mold Processing Based on Intelligence

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Out-of-tolerance is one of the most common problems in mold processing. For the out-of-tolerance problem in mold processing, the cold stamping die for motorcycle fuel tank shell is taken as the research object to solve the problem of out-of-tolerance, that is, easy to occur in the process of mold forming. Based on knowledge engineering, case-based reasoning (CBR) and numerical simulation are combined to study the intelligent design method of stamping die. The factors of overtolerance in stamping die processing are analyzed, and combined with the stamping process, the intelligent design system framework of cold stamping die for fuel tank shells is constructed. Numerical simulation of the double-cover forming (DCF) process of the fuel tank shell shows that sidewall wrinkling and local cracking are the main defects. Through the analysis of orthogonal table data and evaluation indicators, the optimal parameter scheme is $F = 250$ kN and $H = 5$ mm. At this time, the interaction effect ($K2 = 0.738$) of the two is the largest. Through test verification, the distribution trend of the simulated thickness is consistent with the experimental thickness, and the deviation range is within 10%. According to the numerical simulation results, the reasoning mechanism of an intelligent design system including instance and rule knowledge is designed, and an uncertain knowledge reasoning algorithm based on the reliability factor is proposed to improve the accuracy of mold size and reduce the overtolerance of the mold.

1. Introduction

Stamping forming is one of the important processing methods for the production of various sheet metal parts in modern industry. It has the advantages of light weight, high rigidity, high strength, low cost, and high production efficiency, and is conducive to mechanical automation. Forming and manufacturing of sheet metal parts for aircraft, aircraft, consumer electronics, and other products [1–3]. At this stage, the design of stamping die still mainly relies on the accumulated design experience. The design and development of a set of die need to be tested many times. With the maturity and rapid development of numerical simulation technology, artificial intelligence technology, and computer technology in the sheet metal forming process, it is possible to improve the level of stamping process and die design in the industrial field [4–6]. Numerical simulation technology of sheet metal forming process helps designers to optimize process parameters through the analysis of forming process. Knowledge engineering can extract tacit knowledge from a large number of scattered data, making it possible to standardize the acquisition, expression, accumulation, and application of expert individual experience knowledge and simulation knowledge [7–9]. Knowledge engineering integrates KBE and CAD/CAM/CAE modules and communicates information with knowledge bases and databases through artificial intelligence and (Open Database Connectivity, ODBC) methods to realize intelligent design and processing methods. As an effective reasoning method, CBR can describe knowledge in the form of examples, especially in fields, where it is difficult to find laws and models. And the incremental knowledge expansion mechanism makes it have a learning function, and the memory-based knowledge processing method is similar to the problem processing mode of human experts. The application of sheet metal forming numerical simulation technology and artificial intelligence technology in stamping die manufacturing enterprises will greatly reduce the number of mold trials, shorten the mold development cycle, reduce development costs, reduce the impact of human factors on mold quality, and improve the level of mold design, thereby improving the market competitiveness of mold manufacturing enterprises.

2. Causes of Mold Out of Tolerance

The problem of out-of-tolerance mold processing seriously affects the delivery of molds and is one of the main reasons for rejecting molds. The most common quality defect problem in mold processing is that the workpiece size is out-of-tolerance, which in turn affects the delivery of mold production [10, 11]. Therefore, it is particularly important to timely analyze the reasons for dimensional out-of-tolerance and put forward corresponding improvement measures accordingly, in order to avoid the occurrence of similar problems in the future, thereby improving production efficiency and ensuring processing quality. Figure 1 is a diagram of factors affecting mold out-of-tolerance.

It can be seen from Figure 1 that the causes of mold out-of-tolerance mainly include six main factors: personnel, machines, measurement, materials, methods, and environment, which are divided into two categories: human factors and nonhuman factors. Combined with the practice of mold production, the reasons for the out-of-tolerance include: (1) basis error; (2) low technical level; (3) operation error; (4) process method problem; (5) document misunderstanding; (6) equipment problem; and (7) damage. Since there are many factors for mold out-of-tolerance that are included in all stages of mold production, it is necessary to adopt an intelligent design and processing system to reduce the out-of-tolerance of production molds, speed up mold production efficiency, and improve mold dimensional accuracy.

Stamping die is special process equipment for processing materials into parts in cold stamping processing. The overtolerance of the die is mainly due to the stamping process and material problems. The intelligent die processing technology can effectively reduce the stamping die. It can realize the intelligent processing of various molds by modifying the design parameters.

3. Theoretical Basis of Intelligent Mold Processing

3.1. Knowledge Engineering

3.1.1. Overview of Knowledge Engineering. Knowledge engineering originated from knowledge-based systems (or expert systems). Similar to the human expert system, the KBS system provides a solution for a given problem based on the limited known knowledge and a preset reasoning mechanism, and the relevant domain knowledge is stored in a specific knowledge base [12–14]. In order to reuse the information stored in the knowledge base using the inference mechanism, the domain knowledge must be structured, and the rules and frame-like representations are the two main methods of knowledge representation.

3.1.2. Architecture of Knowledge Engineering. Knowledge engineering is an intelligent processing technology that uses the driving and multiplying functions of knowledge to solve problems in engineering and give better solutions. The KBE system analyzes and summarizes the knowledge and experience of professional domain experts, and implements intelligent reasoning decisions based on reasonable knowledge strategies and specific product models so that domain experts can solve professional problems [15–17]. Figure 2 is the structural frame diagram of the KBE system. The system expresses the relevant parameters through knowledge extraction based on the knowledge base by inputting the basic information of the mold, including size, performance, cost, and appearance. Using the path analysis of the knowledge parameter acquisition, the drawings, models, bills of materials, and costs of the stamping die are output.

3.2. CBR Method

3.2.1. Concept of the CBR Method. CBR method is a method to solve the current design problem using successful design solutions that solved similar design problems in the past [18]. By analyzing the die stamping domain ontology, the method expresses the knowledge of die design through domain ontology and rules, defines the knowledge element of the design process, and is driven by the knowledge element of the design process to match the specific association matrix and inference rules in the design process. The design process of dynamic decision is completed.

3.2.2. Application of the CBR Method in Mold Processing. Since the CBR method can well meet the knowledge processing requirements of the mold industry, CBR technology has been well applied in the field of mold design. Jiang et al. [19] described CBR as a cycle consisting of four steps of retrieval, reuse, modification, and retention. Since the CBR method was proposed, a large number of researches have been carried out at home and abroad, and a large number of studies have shown that the CBR method is a promising knowledge-based product design method. Pan [20] proposed a CBR-based fixture design method. This method expresses the knowledge of die design through domain ontology and rules by analyzing die stamping domain ontology, defines the knowledge element of the design process, and is driven by the knowledge element of the design process. The specific correlation matrix and inference rules in the design process are matched, and the design process of dynamic decision-making is completed. Xu [21] carried out casting mold design using CBR. Yuan et al. [22] proposed the use of ontology technology, using domain ontology as the basis for constructing a knowledge base, and specific instance knowledge is expressed as instances of ontology concepts, through which design knowledge in different domains can be shared. Wang [23] proposed a CBR-based casting mold design method. The domestic CBR research started late, and the application of CBR technology to the mold industry is less. At present, the Institute of Mold Technology of Shanghai Jiao Tong University has carried out

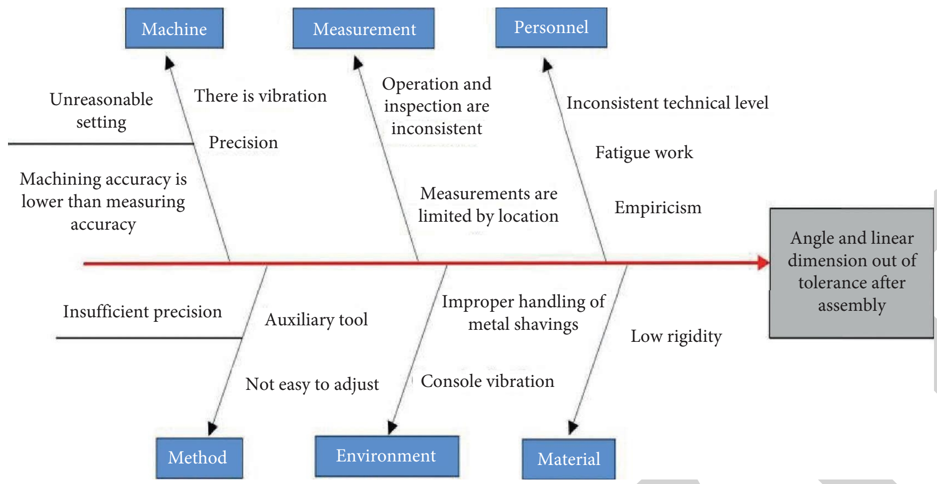

Figure 1: Classification of mold out-of-tolerance factors.

research in this aspect and has achieved certain results in the aspects of injection mold, cold extrusion, and progressive die design [24–26]. Fan and Chen applied case-based reasoning (CBR) technology to stamping die CAD according to the characteristics of mold design relying on experience, and making full use of existing design schemes for reasoning design, which can greatly improve the design efficiency of molds [27, 28].

4. Mold Intelligent Processing Design System Framework

Knowledge-based cold stamping intelligent design is oriented to the entire stamping design process. Applying existing empirical design knowledge and standardized specifications, combining AI and KBE technology, building a complete and reusable knowledge management module, and establishing an application design that conforms to engineering design thinking module, and automatically complete the entire stamping process and die design under the action of effective control and solution mechanism.

4.1. Analysis of Stamping Process and Functional Requirements of Motorcycle Fuel Tank Shell

4.1.1. Analysis of Stamping Process of Motorcycle Fuel Tank Shell. Due to the shape characteristics of the front high and low back, large front and small back, wide front and narrow back, the fuel tank casing has a large elongation rate of the front material, while the tail is basically not extended, and it is easy to cause the front convex part to break and the tail to wrinkle. In the process of forming, the enterprise mostly adopts the double-piece combined forming method. The most critical process is the drawing process, and its design involves issues such as process analysis, process patching, and drawing bead design. The design difficulties are prominent, which seriously restricts the overall quality of the product. The determination of the trimming line in the trimming process is closely related to the process of surface repair. Due to the inconsistency of the trimming direction, the pre-repair and separation processes are set in the process. The effect of trimming also affects the subsequent seam welding process. Roll welding has high technical requirements, and it is very important to control the degree of polishing. Overpolishing will lead to cracks and oil leakage, while insufficient polishing will leave marks.

4.1.2. Analysis of Functional Requirements of Mold Intelligent Design. The intelligent design of cold stamping relies on the rich experience and knowledge of domain experts. The meaning of realizing its intelligence is to meet the design needs of users, and use the existing knowledge to realize the automatic design of formability analysis, process plan decision, process part analysis, and mold assembly. The following is a brief analysis of the functional requirements for the intelligent design of stamping and forming of fuel tank shell parts:

(1) Integration of the geometric and topological information of the fuel tank and related process knowledge.

The stamping and forming design of fuel tank parts involves a large number of information resources including design standards, geometric configurations, calculation methods, process design knowledge, and expert decision-making knowledge. How to combine and integrate these resources and achieve a clear hierarchical structure is an important function that the oil tank shell stamping process and the mold intelligent design system should have.

(2) Effective knowledge acquisition, expression methods, and data processing methods.

The core of knowledge-based intelligent design is to rationally utilize abundant knowledge and data information on the basis of integrated information level. This knowledge is also the basis for intelligent decision-making and evaluation. How to obtain a large amount of implicit latent knowledge required

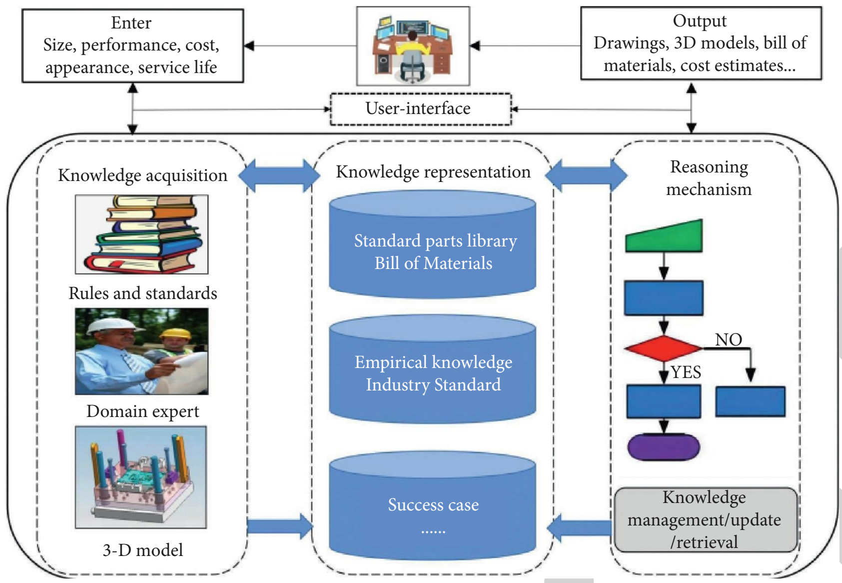

Figure 2: KBE system structure frame diagram.

in the process design of the fuel tank shell, how to deal with the messy data left by the numerical analysis of the fuel tank shell process, and how to express the knowledge information required for the design of the fuel tank shell, these are also knowledge-based fuel tank shell stamping Important functions that an intelligent system should have.

4.2. CSPDIDS-TC System Framework. According to the analysis of the functional requirements of the cold stamping process of the fuel tank shell and the intelligent design of the mold, this chapter constructs the system framework of the cold stamping process of the fuel tank shell and the intelligent design of the mold as shown in Figure 3. The system mainly includes the user interactive interface, application design submodules, There are four subfunction modules of the inference decision module and the knowledge data integration module.

4.2.1. Application Design Module. This module mainly includes three parts: product knowledge integration modeling, knowledge-based process design, and mold structure assembly design. These three links of intelligent stamping design are interrelated and restrict each other. Product knowledge integration modeling is the cornerstone of intelligent stamping process design and die structure assembly design. The final effect of die configuration and die depends on the quality of process design. An unreasonable process plan will affect the process from process design to die structure design. This leads to process duplication and extended development cycles.

4.2.2. User Interactive Interface. It mainly provides users with operations such as system display, information input, exchange operations, and structure output. This article uses UG/MenuScript and UG/UISTyler to create a user interactive interface on the UG platform. The user can send a request to the system to call the application server functional components through interactive operations, and the system will drive the knowledge module and control module through the message passing mechanism. Process and mold design are carried out, which realizes the intelligent decision-making process of stamping with human-computer interaction.

4.2.3. Knowledge Data Integration Module. Design an integrated knowledge data platform composed of knowledge base, database, and instance base to provide data support for the system. This paper integrates the knowledge data module with the product model in the application design module, builds the product knowledge integration model of the fuel tank shell, and uses the UG/KF module to realize the expression and interaction of the model, which is a breakthrough in the design of the knowledge integration module.

4.2.4. Inference Decision Module. The reasoning and decision-making module is the brain of the intelligent system to realize intelligent design. The intelligent precision of the system is reflected by the reasoning and decision-making mechanism. The more reasoning and decision-making are in line with human decision-making thinking, the more accurate and practical it can show. This paper is based on other modules. It focuses on its reasoning control strategy and explores how to make better use of experts' experience knowledge and tacit process knowledge to drive decision-making. Therefore, the uncertainty reasoning method of credibility is introduced. These functional model submodules are relatively independent, but they are related to each other, call each other, complement each other, and are indispensable.

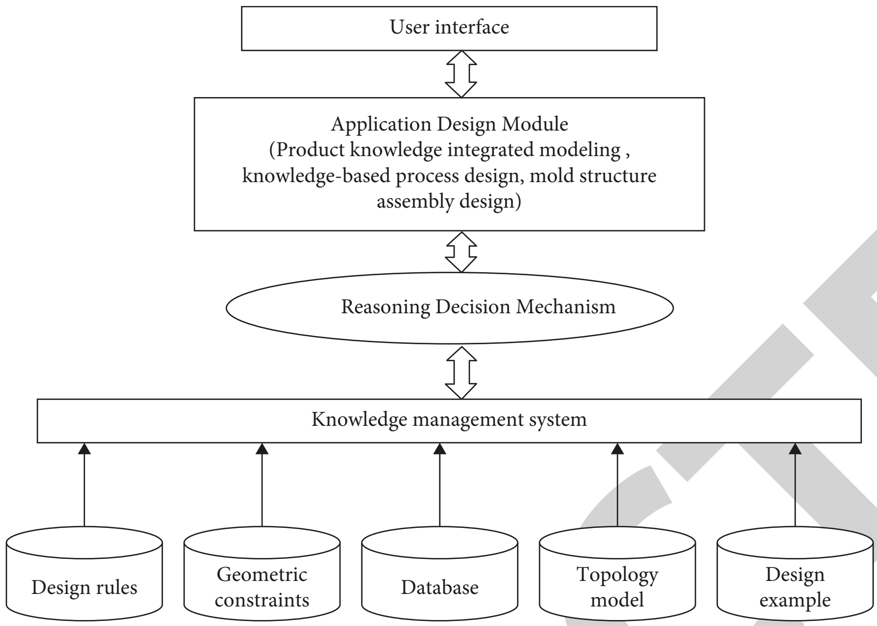

Figure 3: Frame diagram of the cold stamping process of the fuel tank shell and the intelligent design system of the die.

5. Numerical Analysis of Out-of-Tolerance of Fuel Tank Shell Parts

5.1. Theoretical Basis for Numerical Analysis of Stamping Die Out of Tolerance. In the interior of the stamping, deformation die blank, when a certain area of the blank is subjected to excessive tensile stress, the local area of the blank will be severely thinned, causing the blank to be cracked and scrapped. When a certain area of the blank is subjected to excessive compressive stress, reaching the critical stress will reduce the internal stability of the leather and cause wrinkles.

The numerical simulation of stamping forming usually adopts the algorithm of a 4-node quadrilateral thin shell element, which mainly includes the Belytschko–Tsay algorithm and the Hughes–Liu algorithm [29]. The numerical analysis in this section adopts the classic 3-parameter Barlat material model. The 3-parameter Barlat material model mainly combines the influence of the thick anisotropy and anisotropy of the material on the yield surface, and finally, a reliable analytical structure can be obtained, and the power exponential hardening model and linear hardening models can be used as the hardening models for their materials. It takes a psychotropic yield criterion of the form:

$$\begin{aligned}\Phi &= a\left|K_1 + K_2\right|^m + a\left|K_1 - K_2\right|^m + (2-a)\left|2K_2\right|^m = 2\sigma^{-m},\\ K_1 &= \sigma_x + h\sigma_y/2,\\ K_2 &= \sqrt{\left(\sigma_x + h\sigma_y/2\right)^2 + q^2\tau_{xy}^2}.\end{aligned} \tag{1}$$

In the formula, x, y, and z are the rolling direction and transverse direction of the sheet; a, h, and q are the material coefficients of plastic anisotropy; m is the Barlat index; and σ is the equivalent stress along the rolling direction.

Here,

$$a = 2 - 2\sqrt{\frac{R_0 R_{90}}{\left(1+R_0\right)\left(1+R_{90}\right)}} \quad h = \sqrt{\frac{R_0\left(1+R_{90}\right)}{\left(1+R_0\right)R_{90}}}. \tag{2}$$

In the formula, the anisotropy parameter (take 0°, 90°) is as follows:

$$R\phi = \frac{2m\sigma_y^m}{\left(\partial\Phi/\partial\sigma_x + \partial\Phi/\partial\sigma_y\right)\sigma_\phi} - 1 \tag{3}$$

5.2. Numerical Analysis of Drawing Forming of Fuel Tank Shell

5.2.1. Tool Modeling for Cold Stamping of Tank Shells. According to the supplementary principle of process surface and the principle of the setting of draw bead, the process supplementary surface and draw bead are reasonably designed. Numerical simulation models of die, sheet metal, blank holder, and punch are established. The die and punch should be simulated with rigid surfaces, modeled with shell elements, and the mesh adopts adaptive technology. The maximum size of the tool grid is 20 mm and the minimum size is 0.5 mm. After the mesh of the concave die is formed, the offset (OFFSET) method is used to ensure that the gap between the convex and concave die is 1.1 times the thickness of the material, and the offset distance is 0.88 mm to form the mesh of the punch and the blank holder, and then automatic positioning.

5.2.2. Working Condition Setting and Defect Analysis. In the mold manufacturing process, 08 steel or 08F steel material with a thickness of 0.8 mm is usually used, so DQ (36) material is used in DYNAFORM, and the three-parameter Barlat material model is selected. The properties are shown in Table 1.

Table 1: Material parameter table.

E (MPa)	μ	ε_0	k	n	m	ρ (kg/m^3)	Anisotropy index		
							R90	R45	R00
207	0.28	0.0086	0.5407	0.21	6	$7.85e-06$	2.1	1.32	1.66

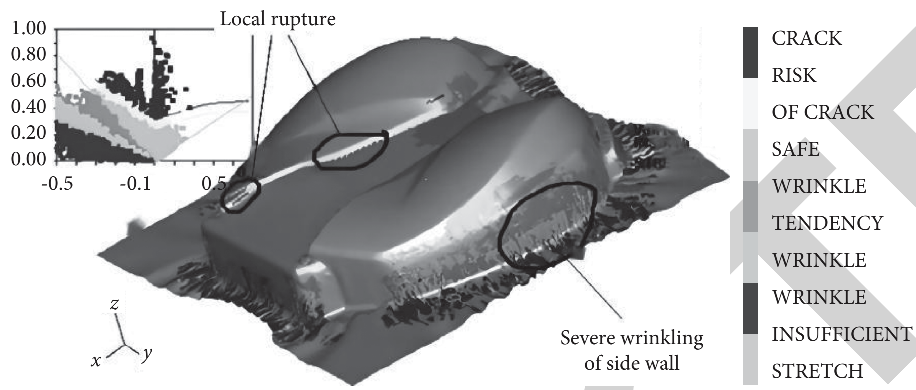

Figure 4: Stamping forming limit diagram.

During the model definition process, the die speed was set to 2000 mm s^{-1} during the closing phase. In the drawing stage, set the speed of the die to 2000 mm·s^{-1}. The blank holder force F is 250 kN, but due to the presence of lubricating oil, the friction coefficient will be set to 0.125 [30]. The limit change after processing and forming is shown in Figure 4.

It can be seen from Figure 4 that it is difficult to feed in the place where the fillet of the die of the fuel tank is small, resulting in severe local reduction, thinning, or even rupture. From the product design point of view, the inclination angle of the straight wall here is too large, and the radius of the transition fillet is also small, which easily causes the stress in the force transmission area to be greater than its bearing capacity. The mold designer usually negotiates with the customer whether the model can be modified without changing the fillet radius, and the inclination of the straight wall can be reduced as much as possible. If the customer insists on this model, it can only be used to make incisions at the appropriate position of the process supplementary surface. The flanges and side walls were severely wrinkled. Flange wrinkling is caused by a combination of radial tension and hoop compression, and the flange portion is removed as waste in the subsequent trimming process. The possible cause of side wrinkling is that the blank holder force is small or the drawing resistance is small, which causes the material to flow into the die and is not supported. The compressive stress in the x direction is much larger than the tensile stress in the y direction, causing local compression instability. Increase the blank holder force or increase the tensile resistance to increase the y-direction tensile stress in the plate and eliminate wrinkles. However, the use of excessive blank holder force and increased drawing resistance will cause serious thinning at the front of the fuel tank, and the sheet will be deformed in a bulging manner. If the thinning exceeds the forming limit, cracks will occur.

5.3. Orthogonal Test Analysis and Molding Process Parameter Analysis

5.3.1. Scheme Design and Simulation Results. The blank holder force and draw bead height were optimized and analyzed by OED method to improve sidewall wrinkling. OED is a design method to study multi-factor and multi-level. It selects some representative points from the comprehensive test according to the orthogonality, and these representative points have the characteristics of uniform dispersion. The blank holder force F is in the range of 200–300 kN, the draw bead height H is in the range of 4–6 mm, and 3 levels are set. That is, the blank holder force F is 200, 250, and 300 kN, and the draw bead height H is 3 levels of 4, 5, and 6 mm. The orthogonal table of $L9(32)$ is selected, and the evaluation index of the experimental design is the maximum principal strain value of the crack-prone zone of the front convex part, the node thickness distribution curve of the easily deformed zone, and the node thickness distribution curve of the side wall wrinkling zone. The orthogonal table is shown in Table 2.

5.3.2. Analysis of Forming Parameters. After forming, a section line M is cut in the severely deformed area of the sheet, and the thickness distribution curve of the nodes on the section line is obtained. Cut a section line N in the wrinkling-prone area of the sidewall, and obtain the thickness distribution curve of the nodes on the section line. From the magnitude of the range R in Table 2, it can be seen that the order of parameters affecting the effect is as follows: B (draw bead height) > A (blank holder force) > $A \times B$. With the increase of the values of A and B, the influence effect is gradually enhanced, while the interaction effect of A and B is first enhanced and then weakened, which indicates that when the blank holder force and the draw bead height are

Table 2: Orthogonal experimental design table.

Program	Factor			
	A_i (kN) (blank holder force)	B_i (kN) (draw bead height)	$(A \times B)_i$	The maximum principal strain of the fracturing zone of the convex part
1	1	1	1	$y1 = 0.195$
2	1	2	2	$y2 = 0.267$
3	1	3	3	$y3 = 0.302$
4	2	1	2	$y4 = 0.274$
5	2	2	3	$y5 = 0.380$
6	2	3	1	$y6 = 1.055$
7	3	1	3	$y7 = 0.285$
8	3	2	1	$y8 = 0.783$
9	3	3	2	$y9 = 1.673$
$K1$	0.255	0.251	0.678	
$K2$	0.570	0.477	0.738	
$K3$	0.914	1.010	0.322	
R	0.659	0.759	0.416	

controlled within the appropriate range, the simultaneous effect of draw bead and blank holder force will be obvious.

Figures 5(a) and 5(b), respectively, show the change of the blank holder force when the height of the draw bead is controlled to be 5 mm, and the height of the draw bead when the height of the blank holder is controlled to be 250 kN, respectively, and the distribution of the thickness of the M section is observed. It can be seen from Figure 5 that the blank holder force F and the draw bead height H have similar effects on the forming uniformity. When F and H are too small, the restraint force on the sheet is small, and the average thickness distribution of the curve $F200$ ($H5$) is 0.75 mm. The average thickness distribution of curve $H4$ ($F250$) is 0.80 mm, and the material cannot be drawn or sufficiently drawn, which will affect the strength of the formed parts and fail to achieve the expected forming effect. With the increase of F and H values, the drawing resistance increases, and the edge material gradually flows into the die. The average thickness distribution of curve $H5$ ($F250$) is 0.71 mm, and the sheet is drawn better. When the value continues to increase, the resistance is too large, the feed at the die mouth is blocked, and the local area will be severely thinned or even broken.

Figure 6 shows the thickness distribution of the N-section node after forming, which reflects the sheet material uniformity in the sidewall area as an important indicator for judging wrinkling. It can be seen from Figure 6 that when F and H are small, the average thickness distribution of curves $H4$ ($F250$) and $F200$ ($H5$) is about 0.79 mm, and the fluctuation of the curves is large. It means that the side wall material is not sufficiently drawn, and the wrinkling is also serious, which will weaken the strength of the part. When the values of F and H increase, the thickness of the sidewall tends to decrease, the average value of the thickness distribution becomes smaller, the fluctuation also decreases significantly, and the overall uniformity is better improved.

It can be seen from the above analysis that F and H can act simultaneously to improve the forming uniformity, and if controlled within a reasonable range, it cannot only improve the wrinkling defect of the sidewall but also make the sheet fully stretched, and can avoid local excessive thin. According to the analysis of orthogonal table data and evaluation index, the optimal parameter scheme is $F = 250$ kN and $H = 5$ mm. At this time, the interaction effect ($K2 = 0.738$) of the two is the largest.

5.4. Test Verification. The experiment was carried out on a 400 t single-action hydraulic press. The above optimization results were used in the experiment (the blank holder force was 25 t, the draw bead height was 5 mm, and the die radius was 8 mm), and the sheet size was $930 * 870\ \text{mm}^2$. Other data were same as the simulated data. The working speed of the slider of the hydraulic press is 6~15 mm/s, and the idle speed is 200 mm/s. Draw lines and take points on the actual production parts of the enterprise and the test parts based on the simulation data according to the section line M, and then use a thickness measuring instrument to measure the thickness of several nodes on the section line. The thickness distribution curve is shown in Figure 7.

As shown in Figure 7, the thickness distribution curve of the test piece is smoother and more uniform than the actual production parts of the enterprise, and the thickness value at the thinnest part also increases, indicating that the material flows into the die more uniformly and the forming quality is better improved. Secondly, the distribution trend of the numerical simulation thickness is consistent with the experimental thickness, but the thickness deviation range is within 10%, which confirms the reliability of the numerical simulation results.

6. Design of the Stamping Die Processing System Based on Intelligence

6.1. Overall Design. The traditional CBR method needs to summarize these design results into design examples and perform index coding to facilitate subsequent retrieval. A product design knowledge system must enable the system to reuse knowledge, that is, to achieve the purpose of stamping die design knowledge reuse. Therefore, the system must meet the requirements. In order to facilitate designers to find design knowledge, it is necessary to

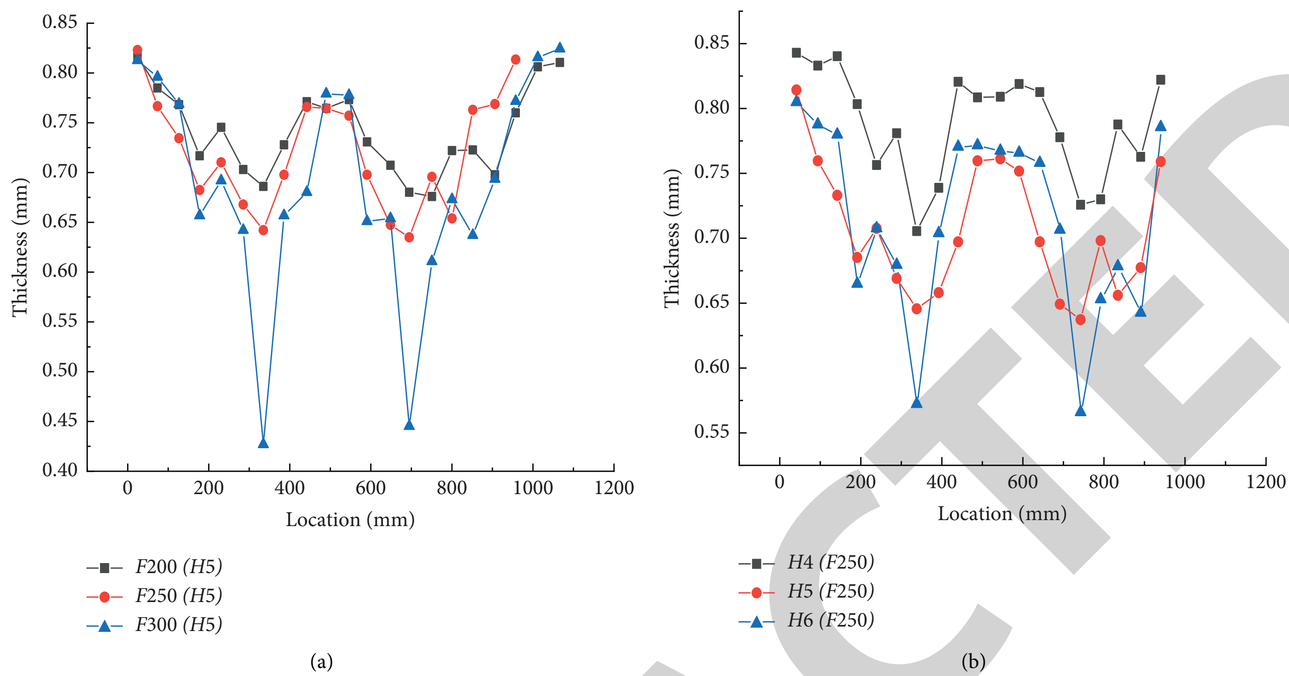

Figure 5: Thickness distribution curve of *M* section. (a) Draw bead height 5 mm. (b) Constant side pressure of 250 kN.

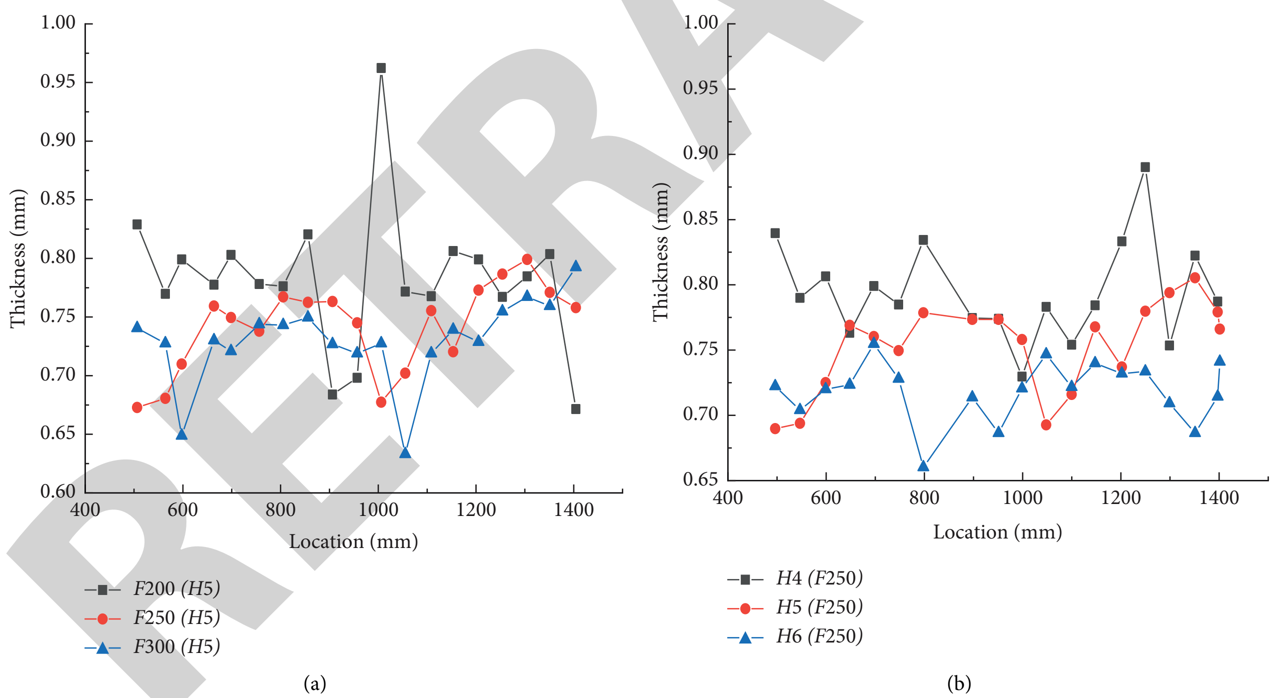

Figure 6: *N*-section thickness distribution curve. (a) Draw bead height 5 mm. (b) Constant side pressure of 250 kN.

establish convenient and practical knowledge management tools to facilitate the management of design knowledge. In order to facilitate the designers to reuse the design results, it is necessary to establish a design knowledge instance database and to save the design knowledge. Design reuse not only includes stamping die design examples but also includes a certain part, or a certain shape model. This paper proposes to use the knowledge graph to formally record and describe the facts of product design results while retaining the four-step cycle of retrieval, reuse, modification, and retention of traditional CBR. According to the above requirements for knowledge representation of stamping die and the characteristics of CBR and knowledge graph, a knowledge representation framework for stamping die design combining CBR and knowledge graph is proposed, as shown in Figure 8. This framework includes the following knowledge representation layer and knowledge operation layer.

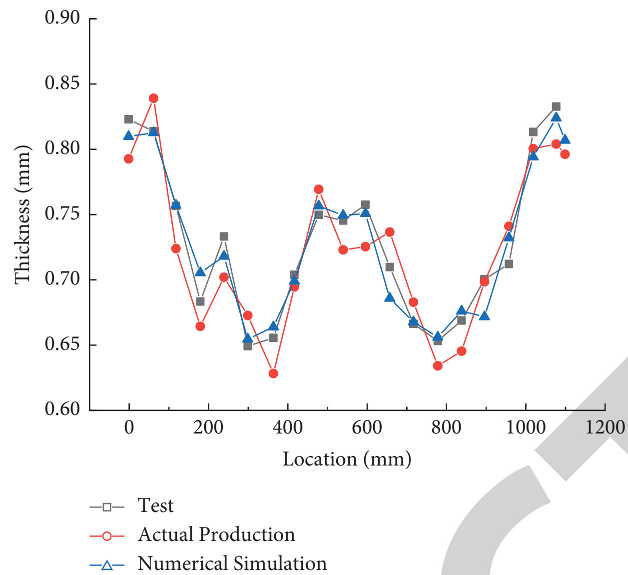

Figure 7: Thickness comparison of test, simulation, and actual production results.

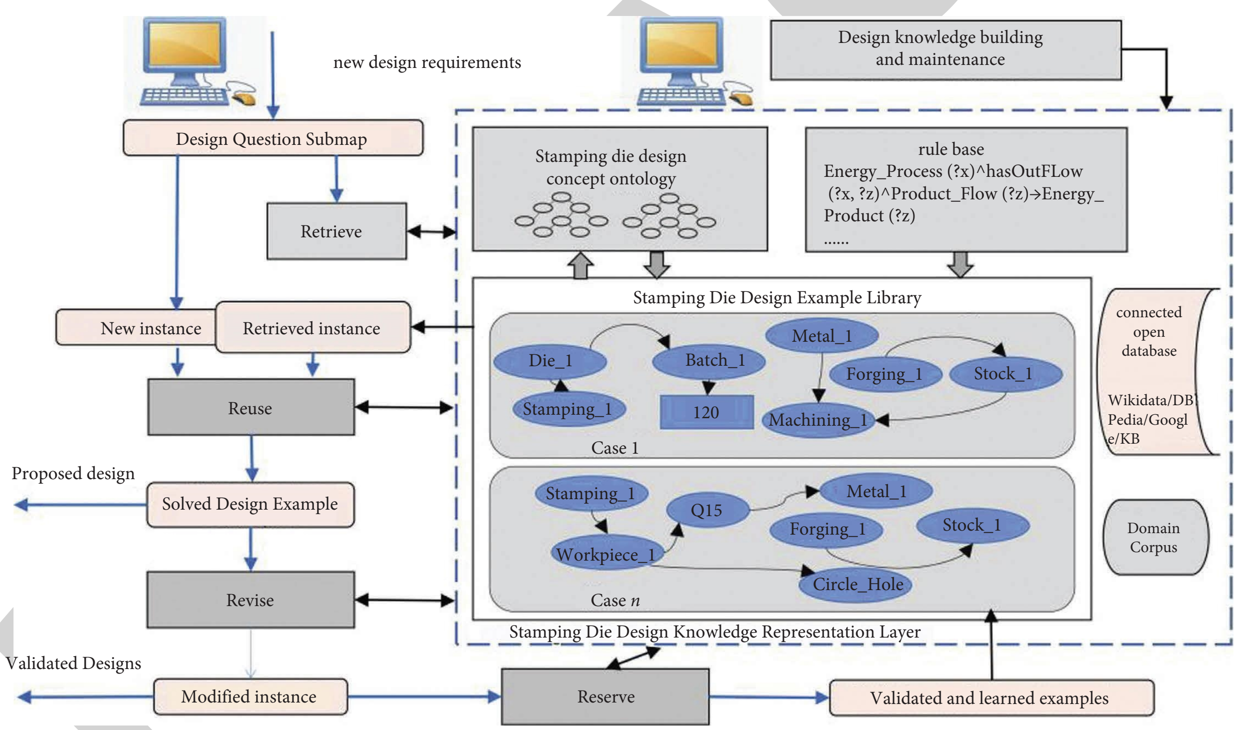

Figure 8: Overall design.

6.2. The Reasoning Method of CSPDIDS-TC

6.2.1. Uncertainty Algorithms Based on Credibility. The reliability CF and the rule threshold t have been introduced in the representation of uncertain knowledge, so we will not introduce them here. For the compound preconditions Ei of the rules, this design introduces a weighting factor to describe the correlation or primary-secondary relationship between the preconditions E_i in the actual uncertainty reasoning has high importance, $0 < \omega_i < 1$, and $\omega_1 + \omega_2 +, \ldots, + \omega_n = 1$:

(1) Uncertainty matching algorithm based on reliability: The rule form for uncertainty inference with thresholds is as follows:

$$IF\, E_1(cf_1, w_1) \cap E_2(cf_2, w_2) \cap \ldots \cap E_n(cf_n, w_n) \quad \text{THEN}\, H(CF(H, E), t). \tag{4}$$

With two sets A and B, the matching degree formula is defined as follows:

$$M(A,B)=\frac{1}{2}\left[(A\otimes B)+(1-A\oplus B)\right]. \quad (5)$$

Here, $A\otimes B=\vee[CF(A_i)\wedge CF(B_i)]$, $A\oplus B=\wedge[CF(A_i)\vee CF(B_i)]$

Suppose you have the following evidence: $T_1(cf_1'),\quad T_2(cf_2'),\ldots,T_n(cf_n')$

The formula for calculating the matching degree between the premise E_i and the evidence T_i is as

$$M^k(E_i,T_i)=\frac{1}{2}\left[\min\{cf_i,cf_i'\}+\left(1-\max\{cf_i,cf_i'\}\right)\right]. \quad (6)$$

According to the rule matching degree $M^k(E,T)$, it indicates the degree $T=\{T_1,T_2,\ldots,T_n\}$ of similarity between the evidence set and the premise set of the kth rule $E^k=\{E_1,E_2,\ldots,E_n\}$, which can also be called rule similarity reading, and its value is calculated by the following formula:

$$M^k(E,T)=w_1\times M^k(E_1,T_1)+w_2\times M^k(E_2,T_2)+\ldots+w_n\times M^k(E_n,T_n). \quad (7)$$

(2) Uncertain transfer algorithm based on reliability:

When the knowledge rules are activated, uncertainty reasoning also requires deducing the credibility value of the conclusion of the activation rules, so as to select the knowledge rules with the highest decision-making ability. For the rules in the knowledge base of the stamping domain, after determining the strength $CF(H,E)$, activation threshold t and the credibility of the rule premise $CF(E)$, the transfer algorithm of the conclusion H credibility is as follows:

$$CF(H)=\left[\omega_1\times\left(\frac{cf_1+cf_1'}{2}\right)+\omega_2\times\left(\frac{cf_2+cf_2'}{2}\right)+\cdots+\omega_n\times\left(\frac{cf_n+cf_n'}{2}\right)\right]\times CF(H,T). \quad (8)$$

6.2.2. Fuzzy Reasoning Based on Credibility Factor. A_i, A_i' are the premise of the rule and the known fact evidence, respectively; CF and CF_i' $(i=1, 2, \ldots, n)$ are the credibility factors, and their range is [0, 1].

In the mode of compound rule premise and compound rule conclusion, a fuzzy relation matrix is introduced, and its specific form is as follows:

$$R=\begin{bmatrix}\gamma_{11} & \gamma_{12} & \cdots & \gamma_{1n}\\ \gamma_{21} & \gamma_{22} & \cdots & \gamma_{2n}\\ \vdots & \vdots & & \vdots\\ \gamma_{m1} & \gamma_{m2} & \cdots & \gamma_{mn}\end{bmatrix}_{m\times n}, 0\le\gamma_{ij}\le 1\,(1\le i\le m, 1\le j\le n). \quad (9)$$

$R(i,j)$ is the probability of the occurrence of the jth premise when the ith conclusion holds. During reasoning, the evidence provided by the user for each premise, the credibility value of the evidence constitutes an n-dimensional vector C, $C=(cf_1', cf_2', \ldots, cf_n')$, $0\le \mathrm{cf}_i\le 1$, n is the number of premises. The inference value of each conclusion in the postinference conclusion set constitutes the vector D, $D_m\times 1=R\cdot C$. After normalizing the D vector, we get $D'm\times 1$.

$$D_{m\times 1}'=\frac{D}{|D|}, D=\left(d_1,d_2,\ldots,d_n\right), |D|=\sum_{i=1}^{m}d_i. \quad (10)$$

The confidence of the conclusion represented $D'm\times 1$ by the largest component value in the result vector as the final result of the inference.

7. Conclusion

This paper designs a die intelligent processing system based on knowledge engineering and case reasoning, which can effectively control the stamping die out-of-tolerance. The numerical simulation results of the drawing process of the motorcycle fuel tank shell show that the wrinkling and local cracking of the sidewall are the main defects. Properly increasing the height of the draw bead and the blank holder force can effectively suppress the wrinkling defects. The orthogonal table data and evaluation indicators show that the optimal parameter scheme is $F=250$ kN, $H=5$ mm. At this time, the interaction effect ($K_2=0.738$) of the two is the largest. The test verification shows that the deviation range between the simulated thickness and the experimental thickness is less than or equal to 10%. By constructing the intelligent design system framework of stamping die for motorcycle fuel tank shell, a fuzzy representation method of process rule knowledge based on threshold and credibility and an uncertain knowledge reasoning algorithm based on credibility factor is proposed to effectively reduce the overtolerance of stamping die.

Data Availability

The experimental data used to support the findings of this study are available from the author upon request.

Conflicts of Interest

The author declares no conflicts of interest to report regarding the present study.

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