# RAPID DESIGN OF MAIZE EAR HARVESTER HEADER BASED ON KNOWLEDGE ENGINEERING
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## 基于知识工程的玉米果穗收获机割台快速设计

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## ABSTRACT

*In the design process of maize combine harvester in China, there are characteristics of customization and high demand for diversification. Aiming at the problems of long design and development cycle, the structural design method of maize combine harvester header based on knowledge engineering is put forward, and the header of maize combine harvester is designed rapidly. Firstly, based on the design standards and specifications of agricultural machinery, the general design process of maize ear harvester header is determined. Secondly, according to the design knowledge and experience, the design method of the core parts of the header is determined, and an example model is established. Finally, based on the platform of MFC and Creo, integrating the design knowledge base, inference engine and parametric model, a rapid design system of maize ear harvester header is constructed. The rapid design of maize ear harvester header is realized, and the design and development efficiency of maize ear harvester header is improved so as to provide technical reference and support for improving the intelligent level of typical complex agricultural machinery equipment in China.*

## 摘要

*我国玉米联合收获机在设计过程中，存在定制化、多样化需求高的特点，针对其设计及开发周期长等问题，提出基于知识工程的玉米果穗收获机割台的结构设计方法，对玉米果穗收获机割台进行快速化设计。首先，在基于农业机械设计标准与规范的基础上，确定了玉米果穗收获机割台的一般设计流程；其次，根据设计知识和经验，确定了割台核心部件的设计方法，并建立了实例模型；最后，在基于 MFC、Creo 的平台上，融设计知识库、推理机和参数化模型为一体，构建了玉米果穗收获机割台的快速化设计系统。实现了玉米果穗收获机割台的快速化设计，提高了玉米果穗收获机割台的设计和开发效率。以期为提高我国典型复杂农机装备智能化水平提供技术参考与支持。*

## INTRODUCTION

With the development of manufacturing technology, the period of agricultural equipment upgrading is becoming shorter and shorter. In the face of fast changing market, it is necessary to improve the efficiency of product design, speed up the overall process of products, and meet the increasingly diversified and personalized needs of users to improve the competitiveness of China's agricultural equipment production enterprises (*Liu Hongxin et al, 2019*). Rapid product design is the development and extension of computer aided design and manufacturing technology. In the current market environment of increasingly diversified and personalized user needs, and a product life cycle gradually shortened, rapid design technology emerges as the times require, which is the urgent demand of many manufacturers (*Wagner P.W., 2017)*. Rapid design means rapid response design and agile design. Its main purpose is to shorten product design cycle, improve product quality and the rapid response ability of enterprises to the market (*Li Changlin et al, 2012*).
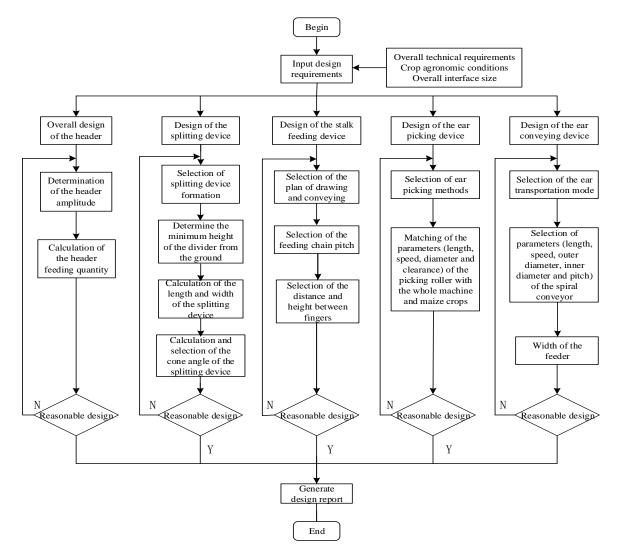
As one of the most important crops in China, maize has high labour intensity in the harvesting process, accounting for 55% of the total input labour (*Geng Aijun et al, 2016*). China's Maize Mechanized Harvesting started late, and because of the diversity of maize planting mode, the development speed of maize mechanization is slow, which still lags behind the level of wheat and rice mechanized harvesting.

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The header of maize ear harvester is the core part of maize ear harvester, and its performance directly affects the whole harvesting performance of maize ear harvester *(Gianfranco La Rocca, 2012)*. During the operation, the maize plants first glide down to the ear picking opening under the function of the divider, the straw feeding device transports the maize plants to the ear picking device, and the ear conveying device transports the maize ear picked to the ear elevator (*Chen Zhi et al, 2014*).

The researches of enterprises and scholars at home and abroad on the maize harvester header often focus on the improvement design of part of the original structure. Such research is often unsystematic and scattered with great limitations (*Cui Tao et al, 2019*). At present, there are still some problems such as the lack of intelligent design ability, design knowledge system and long product development cycle. If the knowledge is collected to build an intelligent rapid design system, it will greatly promote the development speed of products.

In view of this, taking the forward design of maize ear harvester header as the starting point, this paper puts forward the structural design method of maize ear harvester header based on knowledge engineering. The header of maize ear harvester is designed rapidly, and the design process of the maize ear harvester header is established. The classification, expression and storage methods of header design knowledge are studied. A rapid header design system of maize ear harvester is constructed, which integrates the design knowledge base, inference engine and parametric model. The rapid design of maize ear harvester header has been realized, and the design and development efficiency of it has been improved, which is in line with the national medium and long term scientific and technological development planning outline and the "made in China 2025" strategic layout.

## FORWARD DESIGN FLOW OF MAIZE EAR HARVESTER HEADER



**Fig. 1 - General design process of the maize ear harvester header**

Before the design of agricultural machinery, it is necessary to plan its general design process based on design standards and specifications, theoretical analysis and reasoning. General design process is a design method with good generality in a design field (*Qiaosheng Liu et, 2011*). For the design of maize ear harvesting header, the general design process should be carried out under the guidance of maize ear harvesting machine design. Header is the core part of maize ear harvester. Design of the header system is bound to be restricted by the whole machine. Therefore, in the design process, the principle of overall design before subsystem design should be followed; that is, on the basis of determining the whole machine, the core parts can be designed. Combined with the theoretical analysis and design manual of agricultural machinery, agricultural policies and regulations and other relevant design standards and specifications, the general design process of the header is determined (*Tong Jin et al, 2007*) .

Firstly, according to the functional requirements of the header, the design requirements are put forward, including the technical requirements of the whole machine, the agricultural conditions of crops and the interface dimensions of the whole machine. Among them, the technical requirements of the whole machine include line number, line spacing, working width, working speed, sales area, function and performance. Crop agronomic conditions mainly include crop varieties, maturity at harvest, planting methods, row spacing, plant spacing, plant height, ear height, stalk diameter, large end diameter of ear and ear length. The interface dimensions of the whole machine mainly include: the minimum height of ear picking, the maximum height of ear picking, the interface dimensions of ear elevator and power transmission mode.

Based on the modular method, according to the specific header design requirements, combined with the structural characteristics of the header, the header assembly design is divided into the overall design of the header, design of the ear picking device, design of the reel conveying device, design of the splitting device and design of the ear conveying device. The specific design process relationship is summarized as shown in Figure 1. The design of each module is independent when the input design requirements are unchanged. If the scheme is reasonable, the design parameters of the header will be output. If not, the header will be redesigned according to the requirements of the process until the scheme outputs reasonably. When each module meets the design requirements, the design report is generated and presented in the form of Excel. Based on the report, a 3D model is established and saved to the model base.

## CALCULATION OF THE CORE COMPONENT PARAMETERS OF MAIZE EAR HARVESTER HEADER
### Overall design of the header

(1) Calculation of the header cutting width. The cutting width of the harvester header is closely related to the number of rows harvested and the planting row spacing of maize, as shown in Figure 2. The header cutting width meets the following requirements:

$$nB_0 \leq B \leq (n+1)B_0 - 2 \times 90mm \qquad (1)$$

Where: $B$—the cutting width of header, mm; $n$—the harvest number of maize header;

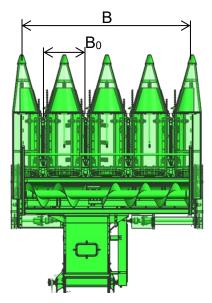$B_0$—the row spacing of maize harvest, mm.



**Fig. 2 - Relationship between the overall width of header and planting row spacing**

(2) Calculation of the header feeding quantity. The feed quantity of the header is an important index to measure the harvesting efficiency of maize harvester, and its calculation is shown in formula (2).

$$Q = (\frac{v}{\Delta l} + 1) \times n \times \Delta m \tag{2}$$

Where: $Q$—the feeding quantity of maize ear harvesting header, kg/s; $v$—the forward speed of combine harvester, m/s; $\Delta l$—the plant spacing of maize, m; $n$—the maize header harvest, row; $\Delta m$—the average quality of harvested maize, kg.

**Design of the splitting device**

During the operation, the maize plant is subdivided at the top of the divider. The maize plants slide along the lower edge of the divider to the middle of it. The reel conveyor feeds the maize plants into the ear picking device. The design of the divider should ensure that the maize plants will not be pushed or broken in the backward sliding process.

(1) Calculation of the cone angle of the divider. In the process of maize harvest, the taper of the divider has a great impact on the quality of it. If the taper design is not reasonable, it is easy to push down the plants and affect the harvest quality.
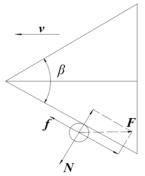


**Fig. 3 - Stress analysis of maize under the action of crop dividing device**

Take the plant as the research object, and the stress analysis is shown in Figure 3. Neglecting the effect of machine speed v on plants, assuming that there is a force F on plants along the opposite direction of speed v, in order to keep maize plants from being pushed down, the stress relationship of plants should meet the following relationship:

$$F \sin \frac{\beta}{2} = N \tag{3}$$

$$F \cos \frac{\beta}{2} \geq f \tag{4}$$

$$f = f_s N \tag{5}$$

Where: $F$ - the force of maize plant, N; $\beta$ - the cone angle of the divider; $N$—the elasticity of the divider to the maize plant, N; $f$ - the maximum static friction of the divider to the maize plant; $f_s$—the friction coefficient between the divider and maize plant. It can be obtained from (3), (4) and (5),

$$f_s \leq \cot \frac{\beta}{2} \tag{6}$$

According to the range of friction coefficient between maize plant and steel material is 0.2-0.6, it is obtained that 30°≤$\beta$≤60°. In order to make the maize plant not be pushed down at any position of the divider, the cone angle of the divider should be designed to be less than 30°.

(2) Calculation of the width of the divider. As shown in Figure 4, maize plants move along the outer surface of the divider from point A at the front tip of it to point B. At point B, the maximum bending angle of corn stalk is $\alpha$. OA and OB are the two limit positions of maize harvest. When the angle between OA and OB is set as $\gamma$, maize plants can just enter the ear plucking device without being broken. At this time, it meets the following requirements:

$$b = 2h \tan \gamma \tag{7}$$

where: *b*—the maximum width of the divider, mm; h—height of the bottom of the divider from the ground, mm.

In order to reduce the ear and grain loss rate of maize, point B is generally lower than the lowest ear point of maize; that is, the height *h* from the bottom of the divider to the ground is smaller than the lowest ear point of the harvested maize. The breaking critical angle of plants should be measured according to the actual situation of local maize harvest. Thus, the allowable value range of the divider *b* can be obtained.
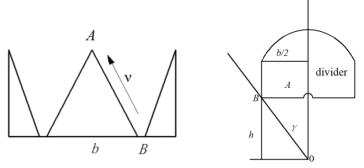


**Fig. 4 - Width and height of the divider**

### Design of maize ear plucking device
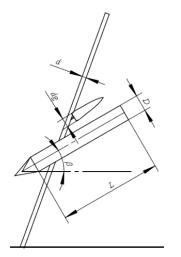
(1) Diameter of the picking roller.



**Fig. 5 - Structure diagram of ear picking device**

The diameter of ear picking roller should meet the two conditions of grasping the maize stalk but not the maize ear (*Geng Duanyang et al, 2017*). According to the above conditions, the structure of the designed ear picking device is shown in Figure 5, and the diameter of ear picking roller shall meet the following formula:

$$\frac{d_g - \delta}{1 - \dfrac{1}{\sqrt{1+\mu_g^2}}} \geq D \geq \frac{d - \delta}{1 - \dfrac{1}{\sqrt{1+\mu_j^2}}} \tag{8}$$

$$h = (0.3 \sim 0.5)d \tag{9}$$

Where: $d_g$—the large end diameter of maize ear, mm; $d$—diameter of maize stalk, mm; $\delta$—horizontal clearance between two picking rollers, mm; $\mu_g$—grabbing coefficient of the picking roller to ear; $\mu_j$—grabbing coefficient of the picking roller to ear; $D$—diameter of picking roller, mm.

Generally, $\mu_j \approx \mu_g = (1.6 \sim 2.3)f = 0.7 \sim 1.1$, where, $f$ is the friction coefficient of the picking roller to the stalk, and the cast iron $f$ = 0.4~0.5.

(2) Length determination of the picking roller.

The minimum length $L_{min}$ of the horizontal ear picking roller should be able to ensure the highest and lowest ear of maize at the position of ear picking. $L_{min}$ can be calculated by the following formula:

$$L_{\min} = L_g \sin \beta \tag{10}$$

Where: $\beta$ is the horizontal inclination of the picking roller; $L_g$ is the height difference between the highest and

the lowest ear of harvested maize.

(3) Linear speed of the picking roller

The linear speed of the picking roller is one of the important factors that affect the picking performance of the device. In the process of operation, if the linear speed of the picking roller is too low, the relative slippage between the stalk and the picking roller is easy to occur, resulting in blockage; on the contrary, the loss rate will increase. Through a large number of experiments, it is found that, when the vertical and horizontal ear picking rollers are working, the ratio K of the forward speed $v_m$ of the harvester to the picking roller $v\sin\beta$ of the horizontal speed $v$ is in the range of 0.7 -1, and the grain loss is relatively low, that is:

$$K = \frac{v_m}{v\sin\beta} = 0.7 \sim 1 \tag{11}$$

Where: $K$ is the proportionality coefficient; $v_m$ is the forward speed of harvester, m/s; $v$ is the linear speed of picking roller; m/s; $\beta$ is the inclination between the picking roller and horizon.

## DEVELOPMENT OF KNOWLEDGE-BASED DESIGN SYSTEM FOR MAIZE EAR HARVESTER HEADER

The header rapid design system is to display the header of maize ear harvester in the form of computer application software. In this paper, 64-bit Windows 8 operating system is selected as the development platform, and visual studio 2012 is selected as the environment. MFC based on VC + + has great advantages in code writing, interface design, database connection and secondary development of drawing software. MFC is selected as the development tool of rapid design system.

The header rapid design system of maize harvester mainly includes header parameter forward design calculation module, model base module and knowledge base module. The working process of header parameter forward design calculation module is as follows: According to the prompts of the design wizard, users determine their own design requirements and convert them into specific parameters to input the design system; The design system starts design reasoning and completes design calculation; after calculation, the results are saved and displayed in the form of design report. The model base module can directly retrieve the corresponding 3D models and instances from the model base according to the input parameters of the personnel, thus greatly simplifying the design process. The knowledge base mainly includes header knowledge involved in the design and calculation process.

**Forward design and calculation module of the parameters of maize ear harvester header**

The calculation module of the header includes two parts: the overall design of header and the design of core components of header. The design of the core components of the header includes the design of the splitting device, the design of the straw feeding device, the design of the ear picking device and the design of ear conveying device.



**Fig. 6 - Parameter calculation interface of vertical horizontal roller ear picking device**

Taking the rapid design of the vertical horizontal roller type ear picking device as an example, Fig 6 shows the rapid design interface of the vertical horizontal roller ear picking device. In the interactive interface, the diameter of maize stalk at the end of maize ear, the diameter of big end of maize ear, the grabbing coefficient of picking roller to the stalk, the inclination angle between the picking roller and the horizontal plane, and the forward speed of the harvester are input. According to the diameter of the maize stalk at the maize ear, the diameter of the big end of the maize ear and the grabbing coefficient of the stripping roller to the stalk, the diameter of the stripping roller and the horizontal gap between the two rollers are determined. The rotation speed of the picking roller is determined according to the inclination of the picking roller and the horizontal plane and the forward speed of the harvester. According to the design experience, the length of each section of the stripping roller and the vertical height difference between the two rollers are selected, and then saved for the next step.

After the forward design calculation, the system can store all the parameters in the design process and directly export the header design parameter report from the rapid design system. The input and output data in the generated parameter report are shown in Tables 1 and 2.

Table 1

**Main input data parameter Report**

| Main input parameters | Numerical value | Unit |
|---|---|---|
| Diameter of ear region of maize stem d | 20 | mm |
| Big end diameter of maize ear $d_g$ | 45 | mm |
| Row spacing of maize planting $B_0$ | 400 | mm |
| Plant spacing of the maize $\Delta l$ | 300 | mm |
| The bending angle of maize plant γ | 22 | ° |
| Average quality of maize ear $\Delta m$ | 0.15 | kg |
| Row number of harvest n | 4 | row |
| Forward speed of harvester v | 2 | m/s |
| Height of the divider from the ground h | 400 | mm |

Table 2

**Main output data parameter Report**

| Main output parameters | Numerical value | Unit |
|---|---|---|
| Feed rate of the header Q | 4.6 | kg/s |
| Width of the header B | 1420 | mm |
| Cone angle of the divider β | 30 | ° |
| Maximum width of the divider b | 323 | mm |
| Bottom length of the divider l | 603 | mm |
| Feed chain pitch of reel t | 40 | mm |
| Finger spacing L1 | 320 | mm |
| Finger height H | 50 | mm |
| Horizontal clearance between two picking rollers δ | 8 | mm |
| Diameter of the picking roller D | 60 | mm |
| Thickness of ear picking plate h0 | 6 | mm |
| Edge bend angle α | 20 | ° |
| Spiral conveyor pitch p | 370 | mm |
| Spiral conveyor speed $n_l$ | 140 | r/min |

**Model base module and knowledge base module**

According to the characteristics of the header design knowledge of maize ear harvester, the design knowledge is divided into formula knowledge, parameter knowledge and selection knowledge as shown in Tables 3, 4 and 5. Knowledge is stored in SQL Server in a certain format. Its main storage tables include serial number, number, parameter, formula content, unit, description and knowledge source. Users can view the required knowledge in the design process.

**Table 3**

**Parameter knowledge base**

| Serial number | No. | Parameter | Minimum value | Maximum value | Explanation | Knowledge sources |
|---|---|---|---|---|---|---|
| 1 | GC_F_01 | Cone angle of the divider β/° | 0 | 25 | general take 15-20 | Agricultural Machinery Design Manual |
| 2 | GC_Z_01 | Angle between the picking roller and horizontal line θ/° | 25 | 40 | general take 30-35 | Agricultural Machinery Design Manual |
| 3 | GC_Z_02 | Length of ear picking section of picking roller l2/mm | 500 | 700 | / | Agricultural Machinery Design Manual |
| 4 | GC_Z_03 | Length of tension section of picking roller l3/mm | 120 | 320 | / | Agricultural Machinery Design Manual |
| 5 | GC_Z_04 | Length of the picking roller L/mm | 740 | 1300 | / | Agricultural Machinery Design Manual |
| 6 | GC_Z_05 | Horizontal clearance of the picking roller δ/mm | 5 | 17 | general take 11-13 | Agricultural Machinery Design Manual |
| 7 | GC_L_01 | Outer diameter of the spiral conveyor D/mm | 350 | 400 | / | Agricultural Machinery Design Manual |
| 8 | GC_L_02 | Pitch of the spiral conveyor p/mm | 340 | 400 | / | Agricultural Machinery Design Manual |
| 9 | GC_L_03 | Rotational speed of the spiral conveyor   n/r/min | 150 | 200 | / | Agricultural Machinery Design Manual |

**Table 4**

**Type selection knowledge base**

| Project type | China 4YW-2 | Yugoslavia ZMAJ-2KM | Yugoslavia ZMAJ-211 | CLAAS KGaA mbH | France Bourgoin |
|---|---|---|---|---|---|
| No. | GX_G_01 | GX_G_02 | GX_Z_01 | GX_Z_02 | GX_Z_03 |
| Type of picking roller or stalk pulling roller | Vertical and horizontal ear picking roller | Vertical and horizontal ear picking roller | maize header (stalk pulling roller) | maize header (stalk pulling roller) | maize header (stalk pulling roller) |
| dip angle of the picking roller β/(°) | 35 | 35 | 30 | 30 | 33 |
| roller diameter(outer diameter/inner diameter)/mm | 94/74 | 72/52 | 94 | 100 | 100 |
| Roll length /mm | 1335 | 1115 | 750 | 480 | 1100 |
| rotational speed of the roller/(r/min) | 750 | 820 | 920 | 1022 | 850 |
| forward speed of the machine/(m/s) | 1.85~2.2 | 1.1~1.4 | 1.94 | 2.2 | 2.2 |
| Peripheral speed of roller/(m/s) | 3.7 | 3.1 | 4.5 | 4.8 | 4.45 |
| Horizontal speed of roller /(m/s) | 2.1 | 1.76 | 2.25 | 2.4 | 2.4 |
| $K=v_m/v\sin\beta$ | 0.87~1.04 | 0.65~0.8 | 0.87 | 0.92 | 0.92 |

<div align="right">**Table 5**</div>

**Formula knowledge base**

| Serial No. | No. | Formula | Explanation |
|---|---|---|---|
| 1 | GG_Z_01 | $(d_g-h)/[1-1/(1+\mu_g2)^{\wedge}(1/2)]\geq D\geq(d-h)/[1-1/(1+\mu j2)^{\wedge}(1/2)]$ | It is used to calculate the diameter of picking roller, with unit mm. |
| 2 | GG_Z_02 | $h=(0.3\sim0.5)d$ | It is used to determine the horizontal clearance of two picking rollers, with unit mm. |
| 3 | GG_Z_03 | $L_{min}=L_g\sin\beta$ | It is used to determine the minimum working length of the picking section of the horizontal picking roller, with unit mm. |
| 4 | GG_Z_04 | $K=v_m/v\sin\beta=0.7\sim1$ | It is used to determine the matching relationship between the linear speed of the picking roller and the forward speed of the machine. |
| 5 | GG_F_01 | $f_s\leq\cot(\beta/2)$ | It is used to determine the range of the divider cone angle. |
| 6 | GG_S_01 | $v_t/v_m=\sin\beta/\sin(\beta-\alpha)=K$ | It is used to determine the matching relationship between the forward speed of the machine and the speed of the clamping conveyor chain. |

The header model base includes header assembly model base, ear picking device model base, splitting device model base and ear conveying device model base. The designer can input the search condition parameters and directly retrieve the corresponding 3D model instances from the model base, and each model base enters the search conditions as shown in the Table 6. For example, if you need to browse the header assembly model base, you can respectively enter the number of lines and ear picking type, browse and call the model. As shown in Figure 7, it is a three-row roller maize ear harvesting header model called according to the search conditions browsing.

<div align="right">**Table 6**</div>

**Search criteria table of model base calls**

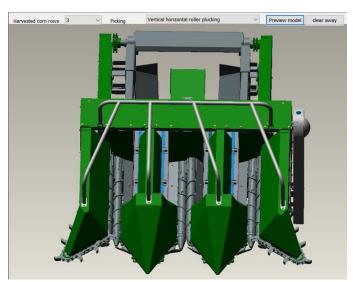| Serial No. | Model base of each component of the header | Condition 1 | Condition 2 |
|---|---|---|---|
| 1 | Header assembly model base | Harvest row number(3-6) | ear picking type of the header(roller type ear picking/ stalk pulling roller type of picking plate) |
| 2 | Model base of the ear picking device | Ear picking type(ear picking roller/ stalk pulling roller) | / |
| 3 | Model base of the splitting device | Divider position(Middle/Both sides of the header) | / |
| 4 | Model base of ear conveyor | Harvest row number(3-6) | Conveying type (to the middle / to one side) |



**Fig. 7 - Three-row roller maize ear harvesting header model**

**CONCLUSIONS**

1. Based on the modular design method of maize ear harvester header, a rapid design system of maize ear harvester header is established. Based on this system, the rapid design process of maize ear harvester header can be organized reasonably.

2. Through the collection and arrangement of a large number of header design data, design standards and specifications as well as the case data of the whole harvester, the header design knowledge is classified and summarized. The calculation method of the core components of the header is established, and the three-dimensional model of the components is established.

3. Based on MFC, a set of knowledge-based rapid design system for maize ear harvester header is established. The system includes header parameter design calculation module, model base module and knowledge base module. The header parameter design and calculation module include the overall parameter design and calculation of the header and the core components. It can quickly realize the calculation of the header forward design parameters, and generate the design report at the same time. The model base module includes the header assembly model base and the core components model base based on the generated design report, which can be accessed quickly. The knowledge base module includes the design knowledge in the design process.

4. The developed knowledge-based rapid design system of corn ear harvester header will play a positive role in shortening the design cycle of corn ear combine harvester, reducing the design cost, improving the product quality and enhancing the market competitiveness in China.

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