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Research and Design of High Efficiency Superfine Crusher using CAD Technology

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Abstract. The objective of this study is to realize the automation and intelligence of the design of highly efficient superfine crusher, and to improve the design quality and efficiency of the crusher. In this paper, the motion and dynamics analysis of the crusher is carried out, and the overall design scheme and program flow of CAD for high efficiency superfine crusher are analyzed. The results show that the efficiency of the optimized crusher is 64.27%, while that of the original crusher is 36.08%, which improves the efficiency by 28.197%. In this paper the parametric design technology is adopted in the CAD system of crusher. The optimal design of the high efficiency ultra-fine crusher with the combination of impact type and hammer type is carried out, which greatly improves the design efficiency and quality.

Keywords: Crusher; CAD; Optimization design.
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1 INTRODUCTION

The production of building materials, from raw materials, fuels to semi-finished products, needs to be broken and ground. The overall purpose is categorized into four steps where first is to increase the specific surface area of materials, so as to improve the effect of physical action and the speed of chemical reaction; second is to promote the uniform mixing and the mixing of various solid materials, which is easy to achieve uniform effect in the state of fine powder; third is to improve the fluidity of materials and facilitate storage and transportation; forth to increase the output, If the cement clinker and gypsum are ground together into the final product, the finer the grinding particle size and the larger the specific surface area, the higher the cement grade [1, 2].

Therefore, it is necessary to improve and improve the crushing operation, reasonably select the crushing process and improve the grinding machinery, which is of great significance to improve the quality and quantity of products, reduce the power consumption and reduce the production cost, that is to say, to achieve high quality, high yield and low consumption [3]. CAD is a new technology formed by the combination of computer science and engineering design. It is one of the most influential application technologies of computer in engineering. It is also an important part of advanced manufacturing technology [4]. Its rapid development and wide application have brought vigorous vitality to the industrial design and manufacturing industry, and made profound changes in the traditional product design methods and production organization mode.

CAD technology provides a powerful technical means for enterprises to shorten design cycle, enhance market adaptability and participate in international market competition, which will continue to produce huge social and economic benefits [5]. Scholars have done a lot of research on screw CADDCAM technology. Authors have developed the parametric design system of the two-dimensional parts drawing of the extrusion screw by using the SolidWorks secondary development principle based on the Visual Basic 6.0 environment and the method of transferring screw parameters through the Access database [6]. In other reported work authors have uses UG as the development platform and Visual C++ 6.0 as the programming tool [7].

At present, there is no dedicated CADDCAM system with complete functions from the rapid creation of the crusher model to the solution of the tool path in the screw machining process [8]. There are many shortcomings in the practical application of two-dimensional drawing in design analysis, which cannot be recognized by the new finite element analysis software [9]. However, when using the finite element software to carry out the finite element modeling analysis, it is necessary to reconstruct the three-dimensional model to make the product more visual, which leads to the lengthening of the development cycle [10]. Recently, some scholars have studied the dynamics of crusher and the dynamic balance of ring hammer by means of measurement test [11].

The rest of the manuscript is organized as the most recent work carried out in the design of superfine crusher using CAD system is described in Section 2. The proposed design methodology including the overall function requirements and other requirements is described in Section 3. Section 4 describes the results and analysis of the system along with the application examples which is followed by the conclusion in Section 5.

2 LITERATURE REVIEW

Modern engineering will need more and more high-purity ultra-fine comminution technology will play an increasingly important role in high-tech research and development. So far, (cannot be synthesized by chemical method) [5]. The main way to obtain ultra-fine powder is still mechanical comminution. The difficulty of superfine grinding and classification technology, which is dependent on mechanical way, is increasing, and the research depth is endless. Superfine grinding technology is the synthesis of various technologies, and its development also depends on the progress of related technologies, such as the processing of high hardness and high toughness wear-resistant components, high-speed bearing, submicron particle size distribution measurement [12].

Since 2000, some experts and scholars have done more in-depth research and test on crusher on the basis of previous research results. For example, in 2006, Guangjun of Central South University introduced the experimental device of ring hammer crusher on the basis of relevant literature on the dynamic analysis of ring hammer crusher, and carried out experimental research on its dynamic analysis by building a ring hammer crusher test system. Finally, the analysis and summary of the experimental results confirm that the dynamic analysis results of the ring hammer crusher can be used as the theoretical basis for its design and calculation [13].

In 2008, the research on dynamic ring hammer of Jiangxi University of technology was carried out. Based on the principle of field dynamic balance, i.e. adding the test weight of the measured mass on the rotor, the influence coefficient at this time is obtained according to the actual measured vibration, and then the unbalance of the rotor is calculated by using the obtained influence coefficient according to the requirements of bearing vibration. In the end, the computer program is written to change the number of dynamic balance equipment. The automatic balancing method is advanced, scientific and effective. Starting from the actual production, through the analysis of single plane dynamic balance and double-sided dynamic balance, the life of the ring hammer can be prolonged by more than one time by using this method, the cost of replacing the ring hammer is greatly saved, and the economic benefit is very obvious [14].

Recently, some scholars have studied the dynamics of crusher and the dynamic balance of ring hammer by means of measurement test. However, there are few researches on the motion simulation and finite element analysis and optimization of crusher by modern design optimization methods. The time of analysis, calculation and design can be greatly saved by using the means of motion analysis and finite element analysis, and the motion track, stress situation and vibration state of crusher can be clearly displayed. At the same time, we can make full use of the results of correlation analysis to carry out rapid and efficient structural optimization design of the crusher, in order to improve the comprehensive performance of the crusher, and also provide reference for the improvement and optimization of similar crushers [15].

The innovation of this paper is to analyze the motion and dynamics of the original crusher, optimize the parameters and structure, and develop a CAD software system based on AutoCAD and VB. In order to realize the automation and intelligence of crusher design, improve the design quality and efficiency of crusher, so as to develop high-quality energy-saving crusher series products.

3 METHODOLOGY

3.1 System Function Requirements

Before establishing the overall structure of the system, the products to be processed must be investigated. Through the analysis of the mechanism and characteristics of the superfine crusher and its transmission mechanism, the main requirements of the superfine crusher CAD system are as follows:

3.1.1 A. Overall functional requirements.

Complete a series of design steps from the original design conditions such as motor selection, and finally to the production of engineering design drawings and technical data of crusher assembly drawings and all parts drawings.

3.1.2 B. Other functional requirements.

The parametric design of each component structure of the ultra-fine crusher is completed; the strength check, safety analysis and life calculation of the moving parts of the ultra-fine crusher are completed; the human-computer interaction environment is friendly, and the use is convenient and reliable.

3.1.3 C. The design of back guard and sieve plate.

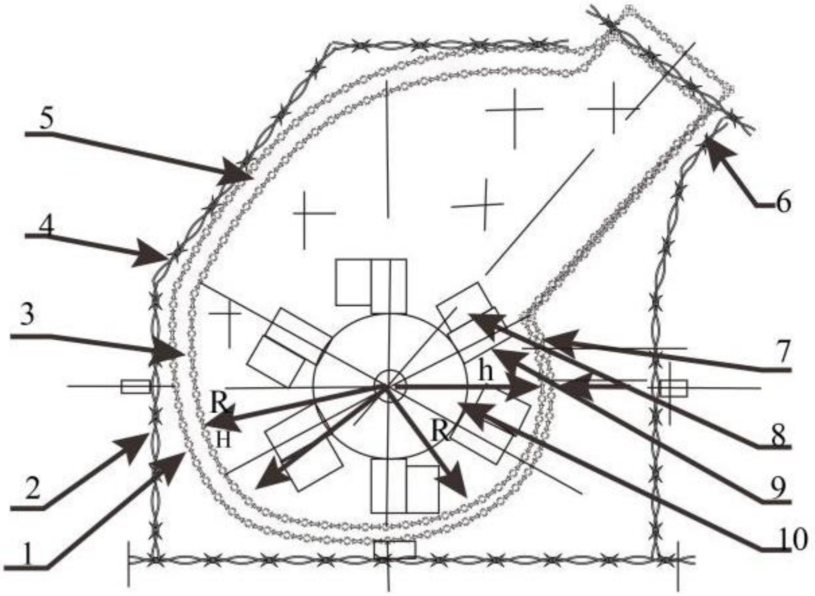
The design of rear-guard plate and sieve plate is a constant force adjusting mechanism, which can effectively control the discharge particle size and improve the utilization rate of hammer head by adjusting the back guard plate and sieve plate after the hammer head is worn.

3.2 Structural Design

In this paper Crusher is studied which is a combination of crusher and impact crusher [16], which greatly prolongs the life of vulnerable parts. Its structure diagram is shown in Figure 1 (M25).

3.2.1 Involute impact plate design

The function of the impact plate is to bear the impact and crushing of the material hit by the plate hammer, and rebound the impact broken material back to the hammering area for impact crushing again. The purpose is to ensure that the whole impact process is carried out, and finally obtain the required product size. There are many structural forms of impact plate, mainly including folding line type and arc type.



1.Sieve plate 2.The chassis 3.After the guard 4.On the chassis
5.Counterattack plate 6.Into the bottom 7.Former guard
8.Hammer head 9.The hammer handle 10.Wheel hub

Figure 1: Structure diagram of the proposed design.

3.2.2 The design of back guard and sieve plate

The design of rear-guard plate and sieve plate is a constant force adjusting mechanism, which can effectively control the discharge particle size and improve the utilization rate of hammer head by adjusting the back guard plate and sieve plate after the hammer head is worn.

3.2.3 The design of shunt system

The system can automatically separate the large and small materials and discharge the required materials from the special channel, which greatly increases the output of the crusher and significantly reduces the energy consumption. The life of wearing parts is prolonged.

3.2.4 Design of sieve plate

In this way, the gap between the hammer head and the screen surface changes from large to small, that is, the volume of the lower crushing chamber changes from large to small. It is favorable for extrusion, grinding and discharging, and reduces the invalid power consumption caused by poor discharge.

3.2.5 Design of crushing chamber

The upper crushing chamber is larger than that of ordinary fine crusher, which makes full use of the functions obtained by materials. At the same time, the probability of material collision with each other increases and the wear of hammer head is reduced.

3.2.6 Rotor design

It shortens the invalid length of the rotor spindle, improves the stress state of the spindle and bearing, prolongs the service life of the bearing, increases the moment of inertia of the rotor, makes the equipment run smoothly, and is beneficial to reduce the installed capacity.

3.2.7 Design of hammer head

The structure of the hammer head of the system has been optimized and adjustable structure, which can completely avoid the defect of fracture from the variable cross-section, and the improvement of its surface shape is also conducive to reducing wear; the new wear-resistant alloy is selected to prolong the service life and improve the utilization rate of the hammer head. In order to reduce the manufacturing cost, the rotor diameter is classified and designed ∅ When ≤ 1000mm, the rotor is of solid structure; the rotor diameter ∅ When it is more than 1000mm, the rotor is of spoke structure.

3.3 Overall Structure of CAD System

The system is divided into two parts: design calculation and automatic drawing. Each part has its own system and can run independently. The two parts are divided into several sub modules under the main control module. The module completes the mechanism optimization calculation, working parameters calculation, kinematics simulation, force analysis, belt transmission design, part strength calculation and drawing, etc. through the different calling methods of the main program segment, each sub module can be executed in sequence, and the data exchange and transmission can be completed by mutual setting common variables; It can also directly call any of the modules to execute, and its initial parameters are given input artificially. Using structured programming, it is more flexible and convenient for program debugging, maintenance and use. At the same time, although the modules are independent of each other, they are connected with each other. After entering the crusher CAD system, the user can complete the operation according to the prompts. The data transmission among the functional modules is mainly through the data file connection. The overall flow chart is shown in Figure 2.

3.3.1 Design module

Crusher optimization design program module. This program module mainly optimizes and calculates the quality of hammer head$m$Angular velocity of rotorωThe parameters, such as the moment of inertia of the rotor around the axis and the efficiency of the crusher, can make the crusher have good motion characteristics and crushing effect. The mathematical model of the optimal design with 23 inequality constraints is shown in the following formula 3.1.

$$\begin{gathered} F(X)=\frac{E-E_{\mathrm{r}}}{E} \longrightarrow minXR^{\mathrm{n}}(n=7) \\ \mathrm{s.t}g_{\mathrm{j}}(x) \geqslant 0(j=1,2,\cdots,23) \\ X=[x_1 x_2 x_3 x_4 x_5 x_6 x_7] \end{gathered} \quad (3.1)$$

Where: $\mathrm{E_r}$For the work of breaking, J ;E It is the mechanical energy of the hammer head, J .

It includes the upper and lower limit constraints of variables, geometric constraints, force requirements, energy requirements, hammer head stability requirements, strength requirements of rotor shaft and rolling bearing determined by conventional design and some empirical data.

3.3.2 Force analysis module

The stress analysis module is used to calculate the stress and analysis of each part of the crusher by analytical method, which provides the basis for the strength calculation module.

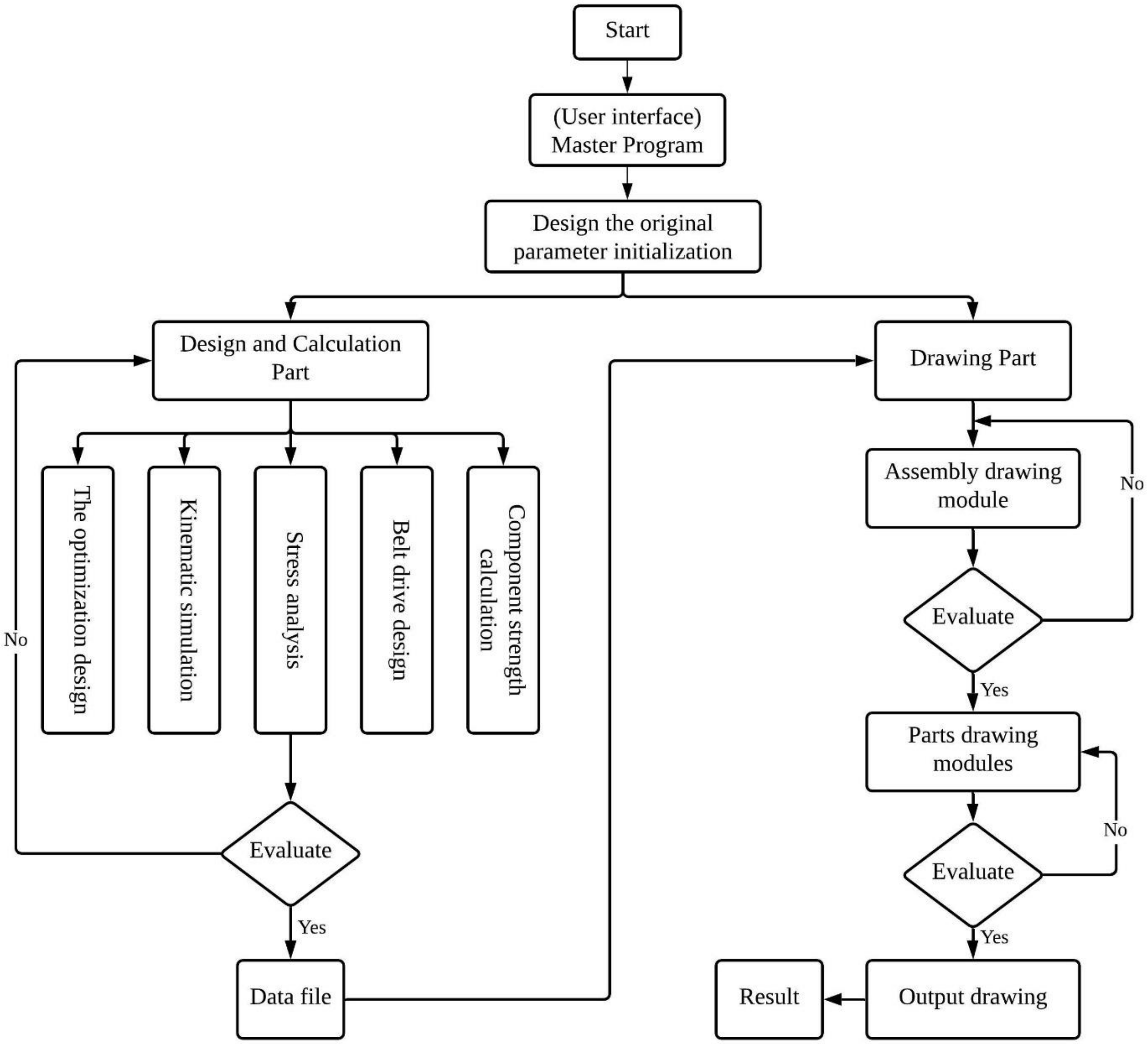


Figure 2: Flow Chart of overall process.

3.3.3 Part strength calculation module

The strength calculation module checks and calculates the strength of main parts, including shaft, frame, handle and head of hammer.

3.3.2 Drawing Module

We use Visual Basic for application to develop parametric automatic drawing module, a total of 59 (8 component modules, as shown in Figure 3).

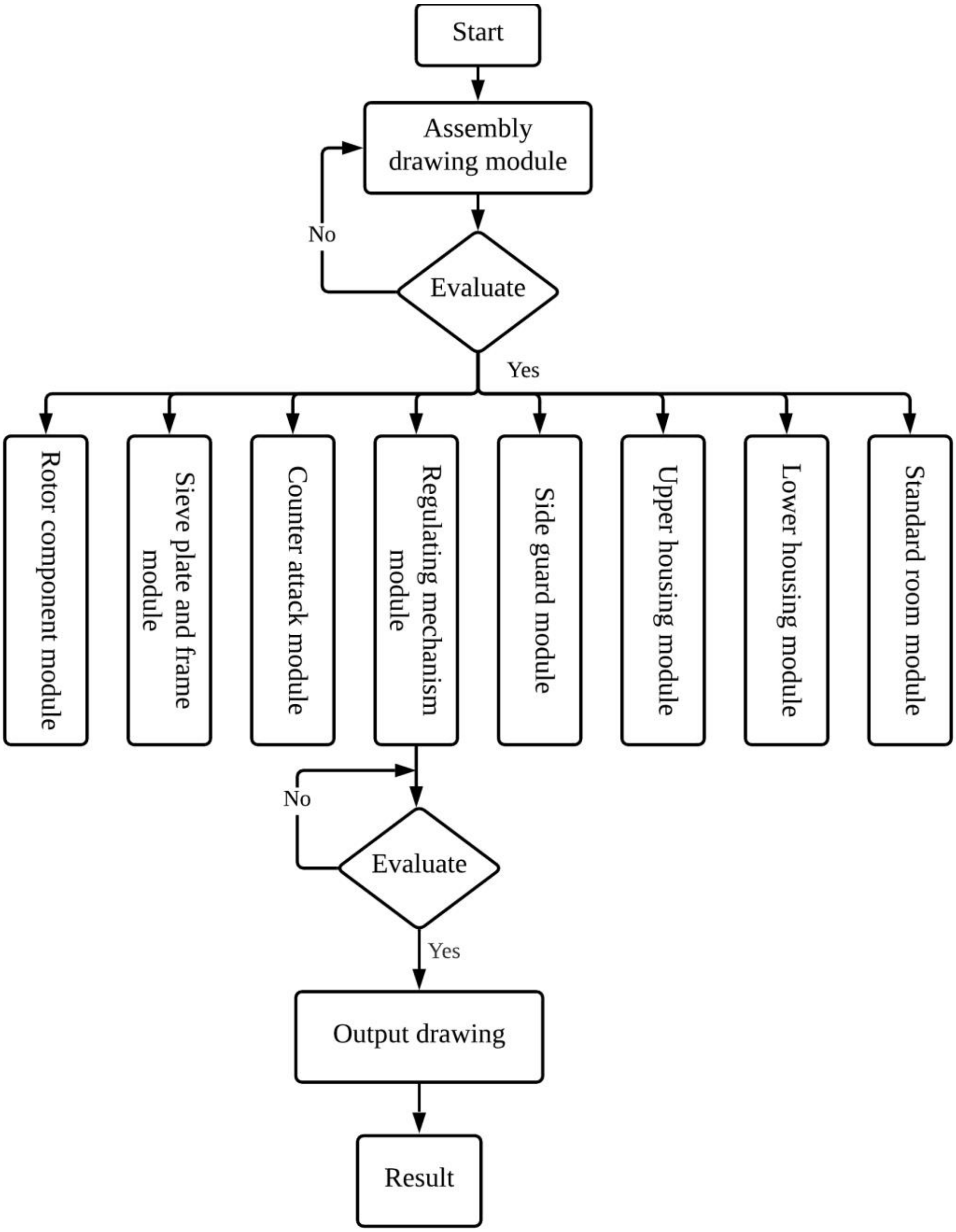


Figure 3: Flow chart of drawing part.

Impact hammer crusher is widely used in industry, and its design is mature product design, belonging to variable parameter design. Feature based design technology is a digital modeling method for describing information and information relationship in the whole process of product manufacturing. There is an explicit relationship between the parameters and the control size of the design object, and the modification of the design results is driven by dimension driven. In production, it is often used for the products with fixed structure and shape. In the process of parametric design, the constraint relationship is found from the existing CAD drawing files, and the fixed size drawings are automatically converted into parametric drawings.

The mathematical model and product structure used in the design of series, general and standardized products are relatively fixed. The only difference is that the structural dimensions of the products are different, and the differences in structural dimensions are caused by the different values of the same number and type of known conditions in different product designs. This kind of product can replace the known conditions and the basic parameters which change with the product specifications with the corresponding variables, and then according to these known conditions and basic parameters, the computer can automatically query the graphic database, and the special drawing software can automatically design the graphics on the screen.

4 RESULT ANALYSIS

4.1 Optimization Design Results

Modern machinery is developing towards high speed, high power, high signal price ratio and intelligence. Volume, weight, efficiency and strength are important indexes of superfine crusher. In order to improve the efficiency and quality of design, designers always try their best to make the performance of their designed products reach the best, such as the most compact structure, the most economical materials, the longest service life and so on. In this paper, the optimal design with energy utilization as the highest objective is discussed under the condition of considering all factors affecting the design of superfine crusher.

The constrained random direction method is used in the optimization process. The advantage of this method is that there is no special requirement for the performance of the objective function m when it is large enough, it will not appear "ill conditioned" like the constrained coordinate rotation method, resulting in the output of pseudo-optimal. In addition, the direction of the step size is the fastest, so the algorithm can choose the fastest direction. If a good initial point can be obtained, the number of iterations can be greatly reduced. The comparison results of optimization calculation and conventional design are shown in Table 1.

Design/Parameters	***M* (Kg)**	***r′* (m)**	***Xc* (m)**	***ω_2* (rad/s)**	***ω_2* (rad/s)**	***S* (m)**	***Ir* (Kg*m^2)**	***F(X)***	***η* (%)**	***V***
Conventional	6.70	0.17	0.10	100.48	80	0.21	10.97	0.63	36.08	38.20
Optimal	8.62	0.14	0.10	124.02	75.15	0.30	12.16	0.35	64.27	54.57

Table 1: Again, short captions should be centered under each table.

It can be seen from table 4-1 that:

(1) In the optimal design, n = 64.272%, while in the conventional design, the utilization coefficient is n = 36.08%, which greatly improves the efficiency of the ultra-fine crusher, thus saving nearly 28.197% of electric energy.

(2) The optimization design pays attention to the selection of the impact point between the hammer head and the rock, effectively controls the impact force of the hammer head, greatly reduces the impact force on the main shaft, improves the service life of the spindle, and reduces the vibration of the machine.

(3) The quality of the optimized hammer head is slightly higher than that of the conventional design, so that the hammer head can break the rock more effectively.

(4) The speed of the optimization design is higher than that of the conventional design, which accords with the energy utilization curve, so that the efficiency can be optimized.

4.2 System Application Example Results

First of all, users double click the shortcut icon of application program on the desktop of Windows operating system to enter the design environment of high-efficiency superfine crusher CAD system. Double click or click "enter" button on the cover to enter the main project interface. There are four options in the main project interface: 1. design calculation part; 2. motion simulation and parametric drawing; 3. parameter query; 4. return to the home page. On the calculation module, there are four parts in the calculation module: calculation module, calculation module, and design module.

Click "return" to the main project interface, click the "motion simulation and parametric drawing" button to enter the AutoCAD system, and click the "crusher" option on the menu to carry out parametric drawing and motion simulation. In parametric drawing, if you need to query the meaning of some parameters, you can find the schematic diagram of corresponding parts in the "parameter query" of the main project interface. Finally complete the whole process of crusher CAD, return to the main design environment of the system for a new round of design work.

Due to the simple design and simple structure and easy to maintain capability makes crusher widely applicable for applications of mining and other mechanical industries. Table 2 represents the material of a components used for the crusher where first column represents the type of components and second column represents the function utilized for each of the components. The components that are used for making of crusher are body, jaw plate both fixed and swing, pit man, flywheel, toggle, rod and shafts.

Material	Component
Main Body Structure	High quality of steel plates
Jaw Plate (Swinging)	Manganese steel
Jaw Plate (Fixed)	Manganese steel
Pitman	Crushers have a light weight pitman having white-metal lining for bearing surface
Toggle	Double toggles, for even the smallest size crushers give even distribution of load
Flywheel	Cast iron of high grade
Rod (Tension)	Pullback rods helps easy movement
Shafts and its Bearings	Massive rigid eccentric shafts made from steel along with roller bearing ensures smooth running

Table 2: Material of the components for crusher.

Figure 4 represents the schematic diagram of toggle crusher where the jaw MN is driven through the shaft AB and it performs simple swing movement. Crusher may be considered as mechanism comprising of four bars where AN represents crank, OA represents link which is fixed, moving jaw represented as MN and toggle bar is OM. Food analysis of kinematics the displacement, velocity at various regions of the swinging jaw plate is analyzed.

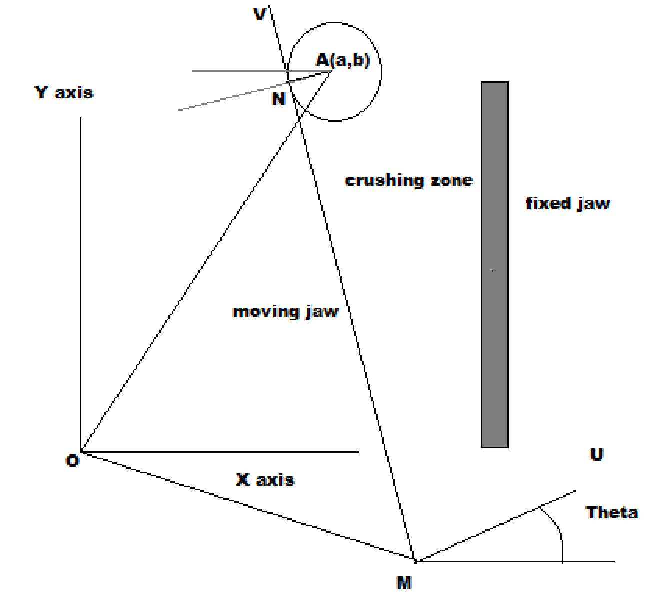


Figure 4: Schematic diagram of crusher.

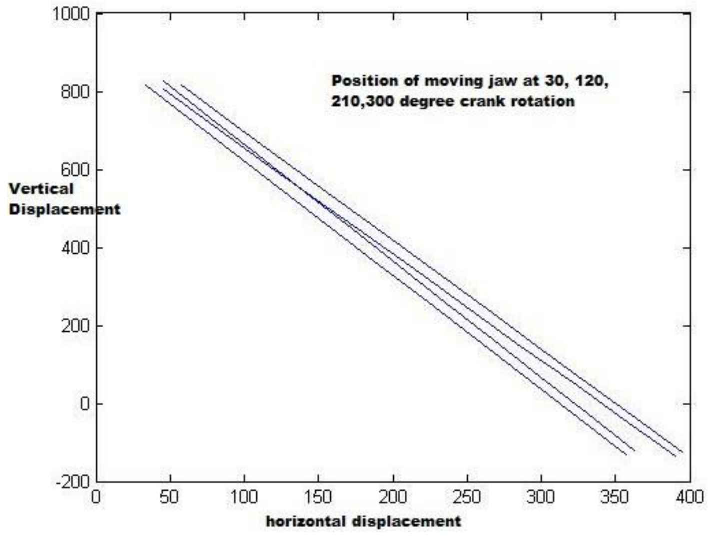


Figure 5: Vertical displacement.

Figure 5 and 6 represents the observations in terms of vertical and horizontal displacement. It is observed from the analysis that an elliptical path is followed by each point on moving jaw. When the model moves towards fixed jaw, the movement is vertically down direction and while returning stroke the moment is in vertically upward direction.

Figure 7 and 8 represents the observations in terms of vertical and horizontal velocity. It is also observed from the analysis that the rate of change in vertical velocity is comparatively high for higher point and then further decreases while moving downwards. The original velocity changes and it is observed higher for the lower point and decreases while moving upwards.

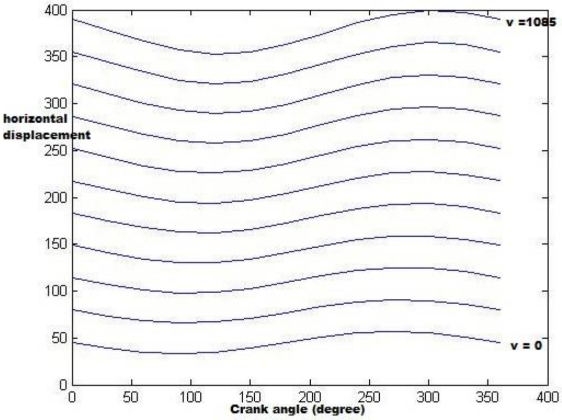


Figure 6: Horizontal Displacement.

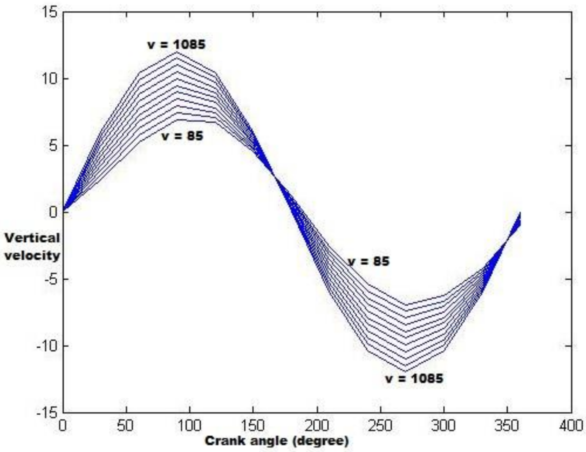


Figure 7: Vertical Velocity

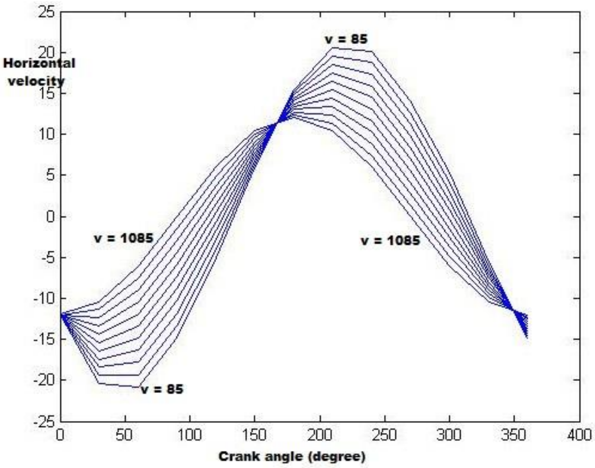


Figure 8: Horizontal velocity.

5 CONCLUSION

This paper is a computer aided design software system based on AutoCAD and VB, which is based on the analysis of motion and dynamics, parameter optimization and structure optimization of the original crusher, and develops new products with excellent performance. First of all, the structural design has been greatly improved, greatly extending the life of vulnerable parts and improving the crushing efficiency. Secondly, the optimal design of the crusher with the combination of impact crusher and hammer crusher is carried out with the highest efficiency as the goal. Based on the comprehensive consideration of various factors affecting the efficiency of crusher, the requirements of force, energy, stability of hammer head, geometric conditions, no motion interference, strength requirements of rotor shaft and rolling bearing, upper and lower limits of design variables are proposed. The key parameters of the crusher (hammer mass m, axis O to pin head contact point R, distance from hammer center to pin shaft and hammer head contact point Xc, distance from hammer head and rock flat collision point to pin shaft and hammer head contact point s, and rotor speed are established ω_2. The optimal design mathematical model of the rotor's moment of inertia about the axis O (IR). Finally, the CAD system of high-efficiency ultra-fine crusher is developed, which combines impact crusher and hammer crusher, and realizes the whole process of original design parameters, optimization design, strength check, belt drive design, assembly drawing, part drawing and motion simulation.

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REFERENCES

[1] Rusiński, E.; Moczko, P.; Pietrusiak, D.; Przybylek, G.: Experimental and numerical studies of jaw crusher supporting structure fatigue failure, Strojniški vestnik-Journal of Mechanical Engineering, 59(9), 2013, 556-563. https://doi.org/10.5545/sv-jme.2012.940

[2] Fang, H.; Yang, J.; Song, Y.; Huang, W.; Chen, J: Simulation and experimental study on the stone powder separator of a vertical shaft impact crusher, Advanced Powder Technology, 31(3), 2020, 1013-1022. https://doi.org/10.1016/j.apt.2019.12.035

[3] Austin, L. G.; Trass, O.: Size reduction of solids crushing and grinding equipment. In Handbook of powder science & technology, Springer, Boston, MA, 1997, 586-634. https://doi.org/10.1007/978-1-4615-6373-0_12

[4] Pregelj, A.; Begovic, M.; Rohatgi, A.; Novosel, D.: On optimization of reliability of distributed generation-enhanced feeders, In Proceedings of 36th Annual Hawaii International Conference on System Sciences, 2003, 6-pp. IEEE. https://doi.org/10.1109/HICSS.2003.1173897

[5] Sun, K.; Ma, R.; Li, G.; Cui, D.; Lu, Y.: The Influence of the Structure of Double Toothed Roller Crusher on the Crushing Effect based on EDEM, In IOP Conference Series: Materials Science and Engineering, IOP Publishing, 423 (1), 2018, p. 012152. https://doi.org/10.1088/1757-899X/423/1/012152

[6] Brière-Côté, A.; Rivest, L.; Maranzana, R.: Comparing 3D CAD models: uses, methods, tools and perspectives, Computer-Aided Design and Applications, 9(6), 2012, 771-794. https://doi.org/10.3722/cadaps.2012.771-794

[7] Jbira, I.; Tlija, M.; Louhichi, B.; Tahan, A.: CAD/Tolerancing integration: Mechanical assembly with form defects, Advances in Engineering Software, 114, 2017, 312-324. https://doi.org/10.1016/j.advengsoft.2017.07.010

[8] Farin, G.: A history of curves and surfaces, Handbook of computer aided geometric design, 1(2), 2002, 2. https://doi.org/10.1016/B978-044451104-1/50002-2

[9] May, L.-G.; Kelly, J.-R.; Bottino, M.-A.; Hill, T.: Effects of cement thickness and bonding on the failure loads of CAD/CAM ceramic crowns: multi-physics FEA modeling and monotonic testing, Dental Materials, 28(8), 2012, e99-e109. https://doi.org/10.1016/j.dental.2012.04.033

[10] Scolozzi, P.: Computer-aided design and computer-aided modeling (CAD/CAM) generated surgical splints, cutting guides and custom-made implants: which indications in orthognathic surgery, Revue de stomatologie, de chirurgie maxillo-faciale et de chirurgie orale, 116(6), 2015, 343-349. https://doi.org/10.1016/j.revsto.2015.09.005

[11] Matros, E.; Albornoz, C.-R.; Rensberger, M.; Weimer, K.; Garfein, E.-S.: Computer-assisted design and computer-assisted modeling technique optimization and advantages over traditional methods of osseous flap reconstruction, Journal of reconstructive microsurgery, 30(05), 2014, 289-296. https://doi.org/10.1055/s-0033-1358789

[12] Cheng, J.; Ren, T.; Zhang, Z.; Liu, D.; Jin, X.: A Dynamic Model of Inertia Cone Crusher Using the Discrete Element Method and Multi-Body Dynamics Coupling, Minerals, 10(10), 2020, 862. https://doi.org/10.3390/min10100862

[13] Russo, D.; Spreafico, C.: TRIZ-Based Guidelines for Eco-Improvement, Sustainability, 12(8), 2020, 3412. https://doi.org/10.3390/su12083412

[14] Jin, H.-Y.; Leng, Q.: Pulley Apply to Metso Nordberg HP500 Cone Crusher Accessories, World Journal of Gastroenterology: WJG, 21(2), 2015, 623. https://doi.org/10.3748/wjg.v21.i2.623

[15] Scott, G.-R.; Turner II, C.-G.; Townsend, G.-C.; Martinón-Torres, M.: The anthropology of modern human teeth: dental morphology and its variation in recent and fossil Homo sapiens, Cambridge University Press, 2018, 79. https://doi.org/10.1017/9781316795859

[16] Fang, H.; Yang, J.; Song, Y.; Huang, W.; Chen, J.: Simulation and experimental study on the stone powder separator of a vertical shaft impact crusher, Advanced Powder Technology, 31(3), 2019, 1013-1022. https://doi.org/10.1016/j.apt.2019.12.035