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Computer-Aided Design AND APPLICATIONS

Design of Die-Casting Die for Engine Cylinder Head Based on 3D Printing and Genetic Algorithm

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Abstract. In view of the structural characteristics and process requirements of the aluminum alloy die casting of the engine cylinder head cover, proposed the design of die-casting die for engine cylinder head based on 3D printing and genetic algorithm, the structural characteristics of the engine cylinder head are introduced and the process analysis is carried out, choose the bottom large plane for assembly datum as the parting surface, the whole set of mold adopts inlay structure in structure, and adopt the oblique stop positioning method. An efficient engine cylinder head design is described for better functioning and long-lasting performance. The operation is easy and safe, the product deforms smoothly, and the mould work is consistent and dependable; it can fulfill continuous production needs, and the product's appearance and interior quality meet design criteria. By installing a stepped crescent-shaped splash block, it can effectively prevent molten metal from splashing and hurting people along the exhaust groove. Realize analog evolution calculations such as binary coding and real-value coding. The encoding method is binary encoding, the population size is 20, the crossover probability is 0.9, and the mutation probability is 0.1, the ending algebra is 300. In the random plan, the connection between parts is 3000, after using genetic algorithm for optimization, the connection of parts is minimized, is 387, the corresponding division scheme is optimal. In use, the operation is convenient and safe, the product is remolded smoothly, and the mold work is stable and reliable, it can meet the requirements of continuous production, and the appearance and internal quality of the product meet the design requirements.

Keywords: 3D; genetic algorithm; engine cylinder head.
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1 INTRODUCTION

The cylinder head cover is an important part located on the top of the engine, it is not only the carrier of the engine camshaft, undertake the high-speed rotation of the camshaft in its shaft hole; Cylinder heads must be long-lasting. To seal the cylinder block through the head gasket, they must withstand exceptionally high pressures and temperatures while preserving their shape and form. They're essential for controlling air flow into and out of the cylinders, along with fuel distribution. The injectors and valves are likewise situated in the cylinder head, which has the most moving parts of the engine. The cylinder head is a crucial portion of your engine that is sometimes overlooked. The cylinder head of an engine is subjected to a variety of loads. These result in numerous engine malfunctions. Overheating cracks are one of the most prevalent cylinder head problems. Cracks between the valves are common, though not always. Oil can seep down into the combustion chamber if your engine has a lot of miles on it and the valve stems or valve guides are worn out. And it is still connected to the cylinder head with pressure and strength requirements, at the same time, multiple components such as intake end cover, exhaust end cover, spark plug, oil dipstick, phase sensor, etc. must be assembled on it [1].

Different qualities and characteristics of the intake charge have been changed as the airflow goes through various components and stages of the intake system to meet the overall aims of the intake charge management system [2, 3]. The intake air filter ensures that the air is clean enough, that the charge air composition and oxygen content are controlled by introducing EGR to the intake air, and that the compressor and charge air cooler meet the intake manifold pressure and temperature objectives, as well as that the intake charge density is within design limits [4, 5]. Valves control the inflow and exhaust of an internal combustion engine.

A spark plug is used in a spark ignition engine. The fundamental function of a spark plug is to transfer a high potential as from ignition system into the combustion chamber, igniting the compressed air-fuel mixture. Therefore, the cylinder head cover bears the dual tasks of connection and strength. Among the earliest module concepts in the field of computer software, point out that the module is a relatively independent computer program that can perform certain functions, and it is interrelated with other programs, at present, the definition of module has been given a broader and deeper meaning, usually refers to a unit, this unit not only has an interface structure, and has a relatively independent function, which is often used as a part of a complex system [6]. Sun, S., etc. define a module as a subsystem, this subsystem has specific independent functions and semi-autonomous, and can be combined with other modules according to certain rules, eventually become a more complex system or product, it can also be decomposed into several modules as a system [7].

With the great development of practical research, modularization has become a new essential industrial structure and organizational model, which is getting more and more attention. The process of splitting a product or system into disposable components is known as modularization. The goal of modularization is to develop a system that is flexible enough to achieve numerous defined configurations while minimizing the number of separate building pieces (module versions) necessary. Maximilian, W. and others believe that tens of thousands of parts and the components and parts composed of these parts constitute the engine, in the process of modularizing engine components, any change in the position of a component or the number of connections will produce a new module division result, therefore, the establishment of an effective and accurate mathematical model is essential for modularization [8].

Alasfour, F. N. and others have used a design structure matrix composed of design parameters based on functional requirements, and the effect is outstanding. Based on the current research, the structural characteristics of the engine cylinder head are introduced and the process analysis is carried out, choose the bottom large plane for the assembly datum as the parting surface, the whole set of mold adopts inlay structure in structure, and adopts oblique stop positioning method [9]. The genetic algorithm is a method for tackling both confined and unconstrained multi - objective optimization problem that is based on natural selection, the mechanism that causes

evolutionary processes [10, 11]. The genetic algorithm repeatedly modifies a population of individual solutions. At each step, the genetics algorithm selects individuals from the current population to be parents and uses them to create the offspring of the next generation. Throughout generations, the population "evolves" toward an optimal solution [12, 13]. The genetic algorithm is used to realize the engine module and complete the automatic optimal clustering process of the module, the connection between the parts is 3000, after the genetic algorithm is used to optimize, the connection between the parts is the smallest, is 387, and the corresponding division scheme is optimal [14].

A genetic algorithm (GA) is an optimization method that solves both limited and unconstrained optimization problems by using a natural selection process analogous to biological evolution. In big production systems, the assembly line problem is a serious concern. A production technique in which parts are sequentially added to workstations until the final assembly is done is known as an assembly line. Each station is in charge of executing a set of tasks on parts that are moving down the line [15, 16]. Mutation is the process of picking a random number of genes from a population and then making random changes to their values in a genetic algorithm [17, 18]. This introduces a random element into the genetic algorithm search process, allowing for a more comprehensive exploration of the search space. Once the chromosomes have been rearranged to form the new population, it, like the prior generation, must be evaluated [19, 20]. In use, the operation is convenient and safe, the product is remolded smoothly, and the mold work is stable and reliable, it can meet the requirements of continuous production, and the appearance and internal quality of the product meet the design requirements. A genetic analysis tool a heuristic is used to solve the model, which takes into account several manufacturing factors such as production volume, different process routes, load factor, material handling, and subcontractor component functionality. This will help to build a strong and sturdy cylinder head that distributes the gas forces working on the head as equally as possible across the engine block. The combustion gas, coolant, and lubricating fluid all flow independently and follow complicated three-dimensional routes in the cylinder head.

2 METHOD

2.1 Structure and Process Analysis of Cylinder Head

The engine cylinder head is a box-shaped part with a complex structure, used to seal the upper part of the cylinder, Together, with pistons and cylinders, it forms a combustion chamber [21]. The cylinder head bears the gas pressure and the mechanical load generated by tightening the cylinder head bolts, at the same time, it is necessary to ensure that the cylinder head has good sealing performance. The material is Y112 high-strength die-cast aluminum alloy, mass production, die-casting forming. The maximum size of the outline is $410mm \times 205mm \times 88mm$ 4, the basic wall thickness is 3mm, the minimum wall thickness is 2mm, the maximum wall thickness is 6mm, for installation and coordination, there is a large flat surface at the bottom and one large hole with a diameter of ϕ28mm, and four holes with a middle diameter of ϕ 22mm, there are requirements for position accuracy between each other, leaving a machining allowance, the entire casting is required to be free of defects such as insufficient pouring, porosity, looseness, cracks, etc.

2.2 Die Casting Mold Design

2.2.1 Selection of die casting machine

The clamping force is the first parameter to be determined when selecting a die casting machine, the clamping force must be greater than the resultant force of the bulging force in the clamping direction, that is: $F \geq KPA$, where K is the safety factor, generally take 1.1-1.3; P is the injection pressure, MPa; A is the projected area of the casting (including the pouring system, overflow trough, etc.) on the vertical plane of the clamping direction, mm^2. Through estimation and

combining the existing die-casting equipment of the factory, Wuxi Xinjiasheng JS750B horizontal cold chamber die-casting machine is selected, the forming force is 7500kN, and the diameter of the pressure chamber is selected as ϕ80mm.

2.2.2 Mold structure design

Due to the large size and complex structure of the product, in the design, a modular structure design scheme is adopted. According to the structural characteristics of the engine cylinder head, and combined with the selection principle of parting surface, select the large plane at the bottom of the cylinder head as the assembly reference as the parting surface. In order to facilitate the processing of parts and the replacement of wearing parts, the whole set of molds adopts inlay structure. Make 5 separate small cores 11 with a ϕ28mm hole and 4 ϕ22mm holes respectively, installed on core 12 by connecting screws, then install it as a whole on the movable mold insert 3 (connected by positioning pins and connecting screws), this constitutes a complete movable mold insert, finally, it is installed on the movable mold cover 10. In order to ensure that the fixed mold and the movable mold are in good position when the mold is closed, the centering method of oblique stop 1 is adopted on the fixed mold insert and the movable mold insert, it can not only guarantee the shape and position requirements of the fixed mold and the movable mold, it can also play a role in reinforcing the cavity. An exhaust groove is arranged on the movable mold insert 3, on the movable mold cover and the fixed mold cover at the corresponding position, all are installed with splash-proof blocks 8, 13, and the cross section of the mating surface is in the shape of a stepped crescent. The purpose is that the gas can be smoothly discharged but can prevent the molten metal from flying out of the parting surface and hurting people. 4 independent cores 6, installed on the fixed mold insert 4, then as a whole and the fixed mold cover plate 7 are installed through positioning pins and connecting screws [22].

2.3 Genetic Algorithm

2.3.1 Selection operator for engine modularization

To do a computational analysis in machine tools planning solutions across multiple component production lines, a modified genetic algorithm technique is applied. A genetic analysis tool heuristic is used to solve the model, which takes into consideration several manufacturing parameters such as volume of production, different process routes, load factor, material handling, and sub-contractors component operation. The genetic algorithm simulates the natural selection process in the biological world; the principle of "survival of the fittest" is also adopted. According to a pre-determined way, some highly adaptable individuals are selected from the parent population of engine modularization and inherited to the next generation. This operator is called the selection operator of engine modularity. Table 1 shows the selection operator.

Serial number	*Name*	*Features*
1	Principles of Roulette	Large selection error
2	Random competition principle	Better choice than roulette
3	Best retention principle	Ensure that the result of the iteration termination is the highest fitness individual in the past
4	No playback random selection	Reduce selection error and inconvenient operation
5	Deterministic choice	Smaller selection error and simple operation

Table 1: Selection operator.

Selection is also known as reproduction; it is the process of selecting individuals with strong vitality in a group to produce a new group. The genetic algorithm uses a selection operator (also known as a reproduction operator) to perform survival of the fittest on individuals in the group. Choose according to the fitness value of each individual, individuals with higher fitness are more likely to be inherited into the next generation population; Individuals with lower fitness are less likely to be inherited into the next generation population [23]. In this way, the fitness of individuals in the group can be continuously approached to the optimal solution. The strategy of selecting the operation has nothing to do with the encoding method. The specific process is as follows: Through fitness calculation, find the best and worst in the current population; Use this highest fitness individual to compare with the highest fitness individual recorded before, if the fitness is higher than the previously recorded fitness, then this individual is selected as the best individual, no cross mutation; Replace this best individual with the worst individual in the current population; Repeat this operation until the number of selected individuals is equal to the number of individuals in the initial population. Sort the individuals in the population in descending order of fitness, among $\lambda+\mu$ individuals, select λ individuals according to the fitness corresponding to $\left(M_i^{(t)}, S_i'^{(t)}\right)$ of a single individual, after determining its selection, its proportion in the mating pool is shown in formula (2.1).

$$p_i^t = G\left(M_i^t, S_i'^{(t)}\right) / \sum_{i=1}^{\lambda} G\left(M_i^t, S_i'^{(t)}\right) \tag{2.1}$$

Then the number of individual $\left(M_i^{(t)}, S_i'^{(t)}\right)$ in the mating pool after selection is shown in formula (2.2).

$$\lambda_i^t = p_i^t \lambda \tag{2.2}$$

If $\lambda_i^t \geq 1$, the number of individual $\left(M_i^{(t)}, S_i'^{(t)}\right)$ in the mating pool is taken as λ_i^t; If $\lambda_i^t \leq 1 1$, take 1 in the order of fitness, until the number in the mating pool reaches λ.

After selection, the λ new individuals in the mating pool are shown in formula (2.3).

$$A_3^{(t)} = \left\{\left(M_{3i}^{(t)}, S_{3i}'^{(t)}\right) \middle| i = 1,2,\ldots,\lambda\right\} \tag{2.3}$$

$A_0^{(t+1)} = A_3^{(t)}$ forms a new generation of populations. Each chromosome is composed of n_c gene fragments, each gene fragment is long n_n, a chromosome represents a spatial division scheme. Randomly determine λ chromosomes, the population that constitutes the engine modularity is shown in formula (2.4).

$$A_0^{(t)} = \left\{\left(M_{0i}^{(t)}, S_{0i}'^{(t)}\right) \middle| i = 1,2,\ldots,\lambda\right\} \tag{2.4}$$

2.3.2 Cross operation of engine modularization

In the genetic algorithm, the individuals in the group must be paired before the crossover operation. At present, the commonly used matching algorithm strategy is random matching, that is to say, M individuals in the group are randomly formed into a [M/2] paired individual group, where [X] represents the largest integer not greater than X [24]. The crossover operation is performed between two individuals in these paired individual groups. The crossover operation between two individuals in a paired individual group, the first determining factor is how to pair individuals in the engine modular group. Table 2 shows the crossover operation. Various genetic algorithm operations are shown in Table 2. A random place on both parents' is chosen and labeled as a 'crossover point'. Right of that location, bits are switched between the two parent chromosomes. This produces two children, each with some genetic information from both parents. The heuristic algorithm mimics the process of natural selection, in which the fittest individuals are chosen for reproduction in order to generate children for the following generation.

Serial number	*Name*	*Features*
1	Single point crossover	Standard genetic algorithm members
2	Two-point cross	Used more
3	Cross evenly	Every bit crosses with the same probability
4	Multipoint crossover	The intersection is greater than 2
5	Heuristic crossover	Application domain knowledge

Table 2: Crossover operation.

Assuming that the maximum number of sub-modules of engine modularization is n_c, the number of nodes is n_n, then the chromosome lengthening is $n_c \bullet n_n$, the crossover process is: independently select two individuals from $A_1^{(t)}$ with the same probability p_c, in $n_c \bullet n_n$, randomly select positions, and interchange the code channel of two individuals at the cross position.

2.3.3 Variation operation of engine modularization

In the process of engine modularization using genetic algorithms, change one or some bit values on the individual code string with a small probability, for example, changing "0" to "1" in binary code, or "1" to "0", the process of generating new individuals is called the variation of engine modularity. In genetic algorithm, the main method of generating new individuals is to carry out the crossover operation of engine modularity. The global search ability of genetic algorithm is determined by it. The auxiliary method for generating new individuals is to carry out the mutation operation of the engine modularity. The local search ability of genetic algorithm is determined by it. There are two main characteristics of the mutation operator in the engine modularization based on genetic algorithm: Improve the local search ability of genetic algorithm. The diversity of the population is maintained, and premature maturity is prevented [25]. Table 3 shows the mutation operator.

Serial number	*Name*	*Features*
1	Fundamental mutation	Standard genetic algorithm members
2	Effective gene mutation	Avoid effective gene deletion
3	Adaptive effective gene mutation	Adaptive change of the number of least effective genes
4	Probabilistic self-adjusting mutation	The similarity of two human strings determines the probability of mutation
5	Uniform mutation	Each real number element changes in the city with the same probability
6	Non-uniform mutation	Make the entire vector slightly change in the solution space
7	Boundary mutation	Suitable for a class of problems with constraints when the best point is at or close to the boundary of the feasible solution

Table 3: Mutation operator.

3 RESULTS AND ANALYSIS

MATLAB is a set of visual numerical calculation system, its mathematical calculation performance is very high, it has a wide range of applications in numerical analysis and matrix operations, graphics processing, signal analysis and other fields. The steps of MATLAB Genetic Algorithm Toolbox (GAOT) to implement genetic algorithms are the same as those of other programming languages

to implement genetic algorithms. It also needs to solve the problems of coding method, establishment of initial group, selection operator, crossover operator, and mutation operator and so on. Therefore, MATLAB's genetic algorithm toolbox is generally composed of 4 key parts: Coding mechanism, fitness function, genetic operator, operating parameters [26]. GAOT realizes and improves GA by writing M files for the basic operations of GA and M files for the main program. It first analyzes the optimization problem, establish an optimized mathematical model, define the fitness function (for constrained optimization problems, you also need to determine the constraint conditions and give the constraint function). Then use the file editor to write these functions into the M file that can return the function value, in this way, the function expression is written into the Matlab system. Finally, execute the M file in the command window to get the optimized solution. Algorithm Toolbox (GAOT) provides a complete solution to various optimization problems. Its concise function expression, arbitrary selection of multiple optimization algorithms, and free setting of algorithm parameters, allows users to use optimized functions conveniently and flexibly. The genetic algorithm toolbox (GAOT) is reasonably structured, it is easy to expand, has the characteristics of simple, easy to learn, easy to use, and easy to modify, it can realize the simulation evolution calculation of binary code and real value code. The encoding method is binary encoding, the population size is 20, the crossover probability is 0.9, and the mutation probability is 0.1, the ending algebra is 300. After selection, crossover, mutation and other genetic operations, the total connection weight of aero-engine modularity is calculated, and the genetic effect diagram is shown in Figure 1. The curve shown in Figure 1 clearly depicts that this operation od casting is convenient and safe, the product is remolded smoothly, and the mold work is stable and reliable. Through the observation, it can be said that this product meets the design requirements.

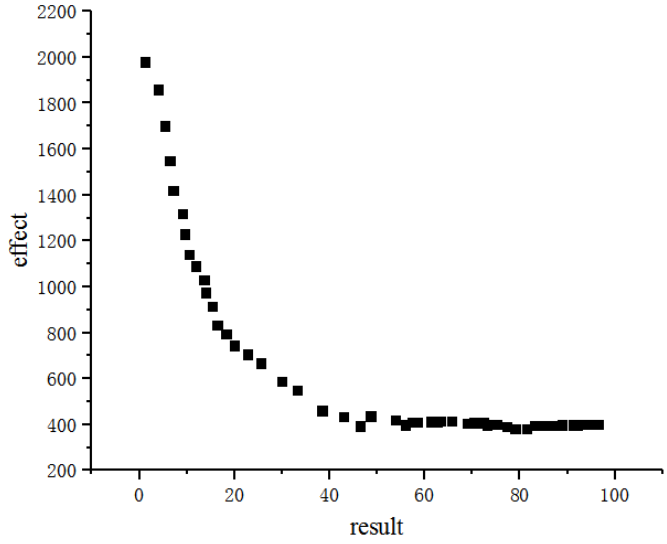

Figure 1: Genetic effect diagram.

The evaluation index of the optimal module division of the engine is the connection between the modules and the connection between the internal parts of the module. The optimal partition scheme is the one with less contact, as shown in Figure 1, in the random plan, the connection between parts is 3000, after using genetic algorithm for optimization, the connection of parts is minimized, is 387, the corresponding division scheme is optimal. Die-casting parts (movable and fixed mold inserts, cores, small cores, sprue sleeves, shunt cones, etc. parts that are in direct contact with molten metal) using H13 (4Cr5MoVSi) die steel, QT500-7 ductile iron is selected for moving and fixed mold sets and connecting blocks, the push rod fixed plate and push plate are made of 45 steel, and the guide post, guide sleeve, push plate guide post and push plate guide

sleeve are made of T10 steel. The H13 steel used in the forming parts has high tempering resistance and thermal fatigue resistance, and also has good nitriding process performance. It can effectively prevent mold sticking and cavity cracking. The blank of the formed part is a forging, and the manufacturing process route is: Forging → stress relief annealing → rough machining → stabilization treatment → finishing forming → quenching → tempering (HRC44~47) → fitter repair and finishing → trial mold → surface nitriding (nitriding thickness is 0.15~0.2mm, the hardness HV is 600).

4 CONCLUSION

Proposed the design of die-casting die for engine cylinder head based on 3D printing and genetic algorithm, after the design and production of the die-casting mold for the engine cylinder head, after debugging and production verification, the genetic algorithm is used to realize the engine module, complete the automatic optimal clustering process of the module, realize analog evolution calculations such as binary coding and real-value coding. An efficient engine cylinder head design is specified for enhanced operating and long-term performance. It can meet continuous manufacturing requirements, and the product's appearance and interior quality meet design parameters. This will assist in the development of a sturdy and long-lasting cylinder head that distributes the gas forces operating on it as evenly as possible throughout the engine block. The encoding method is binary encoding, the population size is 20, and the crossover probability is 0.9 , the mutation probability is 0.1, and the termination algebra is 300. In the randomly developed plan, the connection between parts is 3000. After optimization using genetic algorithm, the connection of the parts is the smallest, which is 387, and the corresponding division scheme is the best. In use, the operation is convenient and safe, the product is remolded smoothly, and the mold work is stable and reliable it can meet the requirements of continuous production, and the appearance and internal quality of the product meet the design requirements. However, there are still many shortcomings in the practicality and depth of the problem, and will continue to be studied in the future.

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