Overview of Numerical Analysis and Optimization Methods for Eddy Current Retarders

Yunfei Liao

Chongqing Industry Polytechnic College, Chongqing 401120, China

Abstract: Aiming at the analysis and optimization of eddy current retarder, this paper reviews the development of numerical analysis based on finite element method. The characteristics of finite element method and the application of numerical method in the analysis of eddy current retarder are briefly introduced. In terms of algorithm, the different applications of multi-objective genetic algorithm, robustness principle, Taguchi algorithm and Rogowski method in the analysis of important parameters of eddy current retarder are introduced and summarized; In terms of software, the application of commercial software in magnetic field and temperature field is briefly introduced; In industrial practice, the development of numerical simulation methods in the research of braking torque is introduced. On the basis of reviewing the numerical analysis and optimization methods of eddy current retarder, the future of its digital design is prospected.

Keywords: Eddy current retarder, Numerical analysis, Finite element method, Optimization design method.

1. Introduction

With the growth of the national economy, the demand for automobile freight is increasing, which makes the transportation industry develop rapidly. At the same time, people have higher and higher requirements for safety [1-3]. They all hope that the brake performance of vehicles will be better and better, and the requirements for comfort will also be strengthened day by day. The demand for the stability of vehicle driving and riding process is also growing. As a very practical auxiliary braking device, the retarder has the characteristics of environmental protection and energy conservation, and appropriately meets this requirement [4-6].

The eddy current retarder has only been introduced from foreign vehicles to large-scale promotion for more than ten years, and now it still occupies an absolute majority of the retarder market. Foreign countries have made great efforts to analyze the characteristics and performance of the eddy current retarder since decades ago, and forced it to be used. Since the end of the 20th century, our country has promoted it through various laws and regulations. With the expansion of eddy current retarder, domestic products have been used in large quantities in the market. Although many universities and enterprises in China have done a lot of work on the R&D and manufacturing of eddy current retarder and various characteristic indicators, in general, the use of eddy current retarder in China is late, and the research on its performance has only begun in recent years.

In this case, the huge cost of experimental testing has become one of the main obstacles to the commercial research of eddy current retarder [7]. Numerical analysis based on the finite element analysis (FEA) method can help enterprises reduce the number of prototypes and test times of prototype testing in the design, optimization or control of products or processes [8]. For enterprises and research institutions, the finite element simulation analysis not only brings about cost reduction, but also more important is to win advantages in the fierce market competition, bringing greater returns for R&D investment. This paper gives an overview of the numerical analysis of retarder, so that researchers can understand its current situation and provide reference for subsequent research.

2. Finite Element Analysis

Finite Element Analysis (FEA) simulates real physical systems (geometry and load cases) by mathematical approximation. By using simple and interacting elements, a finite number of unknowns can be used to approximate a real system with infinite unknowns [9].

Finite element analysis is to replace complex problems with simpler ones and then solve them. It regards the solution domain as consisting of many small interconnected subdomains called finite elements, assumes a suitable (relatively simple) approximate solution for each element, and then deduces and solves the total satisfaction conditions of this domain (such as structural equilibrium conditions), so as to obtain the solution of the problem. Because the actual problem is replaced by a simpler problem, this solution is not an exact solution, but an approximate solution. Because most practical problems are difficult to get accurate solutions, and the finite element method not only has high calculation accuracy, but also can adapt to various complex shapes, it has become an effective engineering analysis method [10].

Finite element is the discrete element that can represent the actual continuous domain. The concept of finite element has been produced and applied several centuries ago. For example, a polygon (finite line element) is used to approximate a circle to obtain the circumference of a circle, but it is a recent thing that it was proposed as a method. The finite element method was originally called the matrix approximation method, which was applied to the structural strength calculation of aircraft. Because of its convenience, practicality and effectiveness, it has aroused great interest of scientists engaged in mechanical research. After just a few decades of efforts, with the rapid development and popularization of computer technology, the finite element method has rapidly expanded from structural engineering strength analysis and calculation to almost all scientific and technological fields, becoming a colorful, widely used, practical and efficient numerical analysis method [11, 12].

3. Development of Numerical Analysis Methods for Eddy Current Retarder

3.1. Beginning of Eddy Current Numerical Optimization Method

In 1998, Norio Takahashi [13], a Japanese scholar, published a research paper on IEEE TRANSACTIONS ON MAGNETICS entitled Optimization of permanent magnet type of retarder using 3-D final element method and direct search method, which opened up a new path to optimize the design of eddy current retarder by combining experimental methods with numerical methods. Norio Takahashi's research points out that the experimental design method and Rosenbrock method are used for 3D optimization design of the permanent magnet retarder. Compared with using only the initial value, the initial value obtained by using the experimental design method can reduce the CPU time.

3.2. Application of Multi-objective Genetic Algorithm

In 2004, A Canova [14] used multi-objective genetic algorithm to optimize the radial permanent magnet eddy current coupler, and analyzed the performance of the device using the magneto dynamic analysis equation.

Canova optimized the radial structure of the eddy current retarder with multiple objectives. In order to speed up the optimization process, the objective function is strictly formulated based on the analytical solution of the field problem rather than the numerical technique. In the current research, the magnetic field is generated by a single side permanent magnet on the stator, and the conductive part is composed of copper or aluminum sheets on the rotor.

Canova conducts field analysis of the device through an analysis model based on variable separation method (VSM). The structure and the most important geometric parameters of the radial model are shown in Figure 1. If the end effect is ignored, the cross section of the device can be studied. According to the VSM method, the magnetic domain needs to subdivide the structure into five regions, namely:

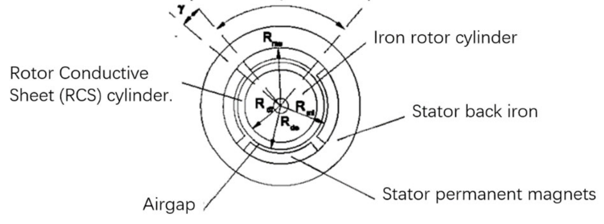

Figure 1. Radial coupler parameter

3.3. Design Based on Robustness Principle and Taguchi Algorithm

In 2006, Niu Runxin [15] and others divided the design of permanent magnet retarder into conceptual design, parameter design and tolerance design based on robust design principles and Taguchi algorithm. With the most stable performance, minimum fluctuation and maximum signal-to-noise ratio as the target, select appropriate parameters as the internal table and parameter fluctuation rate as the external surface. Through the signal-to-noise ratio, find out the best combination of parameters. Tolerance design finds out the contribution rate of each factor to the objective function. Niu Runxin's work has proved the feasibility and effectiveness of robust design. Due to the limitations of test and production conditions and cost factors, most of the controllable factors for selecting the objective function in the internal table are factors that have an obvious analytical relationship with the objective function. This can reduce the cost of testing and sample production. In order to eliminate these unreasonableness, factors without analytic relationship can be considered if conditions permit. After the first round of test, the direction of improvement or promising areas can be found through data analysis. Then, new experiments are designed in new areas. When a combination of robustness parameters is found, a verification test shall be carried out. This is the direction of further research.

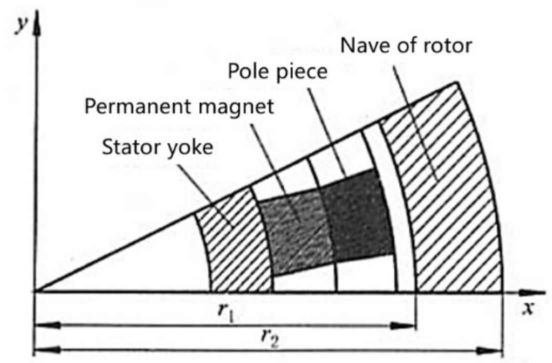

Figure 2. Schematic of permanent magnet type retarder

3.4. Application of Rogowski Method

Zhao Xiaobo et al. [16], in order to study the electromagnetic field distribution of the permanent magnet eddy current retarder, equivalent the permanent magnet of the retarder to the magnetizing current, studied the air gap magnetic field distribution from Maxwell equations, calculated the eddy current density in the rotor drum, and derived the brake torque calculation formula of the permanent magnet eddy current retarder. Their work draws two important conclusions: (1) The two-dimensional analytical model based on Rogowski method clearly reveals the electromagnetic field essence of permanent magnet eddy current retarder, and effectively reflects the influence of structure and operating parameters on eddy current, air gap magnetic flux density and braking torque. It can quickly provide preliminary design data for permanent magnet eddy current retarder. (2) The experiment shows that the Rogowski method is feasible. Using Rogowski method to solve electromagnetic field and braking torque of permanent magnet eddy current retarder is helpful to enrich and improve the calculation method of electromagnetic field and braking torque of permanent magnet eddy current retarder.

Zhao Xiaobo and others pointed out that the equivalent magnetic circuit method and the complex vector magnetic potential method based on the electromagnetic field theory are two analytical methods for calculating the braking torque of the retarder at present. Although the equivalent magnetic circuit method is simple and easy to understand, its calculation accuracy is inferior to that of Rogowski method due to many simplifications and assumptions; At high speed, the calculated results of complex vector magnetic potential method and Rogowski method are basically consistent, and both can better approximate the test curve. At low speed, the calculated results of Rogowski method are closer to the experimental values.

3.5. Application of Commercial Software Such as Ansys

Since 2010, Jiao Bingfeng [17], Qiu Xuyun [18] and others have started to use commercial finite element software such as Ansys to carry out numerical analysis and optimal design of eddy current retarder.

The main purpose of the research of Jiao Bingfeng et al. [17] is to use ANSYS, finite element analysis software and its design optimization module to conduct magnetic analysis on the magnetic equipment of permanent magnetic retarder (PMR) and optimize the structure of the magnetic equipment. According to the structural characteristics of magnetic equipment, the physical model is established as an axisymmetric model. Using this model, the magnetic field distribution and magnetic force are calculated by ANSYS. The mathematical model of structural optimization is established. The design variables are structural parameters, including the dimensions of permanent magnet and yoke; The objective function is magnetic force. The unconstrained optimization model aims at the maximum value of magnetic force. The first order optimization method is used to determine the optimal design of the problem. The optimization process uses ANSYS Parametric Design Language (APDL) completely. ANSYS optimization module provides several tools to deal with mathematical models in different ways. Design tools are used to understand the behavior of design space and dependent variables. The results show that using ANSYS optimization module and its design tools to design the structure is an effective means to improve the structure.

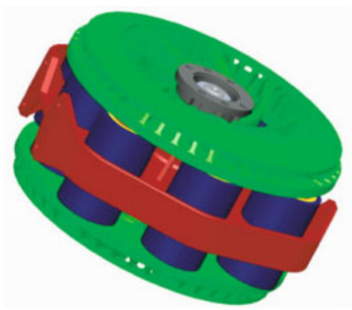

Figure 3. Disk-type PMR structure

Qiu Xuyun et al. [18] used the finite element software ANSYS to analyze the heat distribution of the rotor clutch housing model. They used the finite element software ANSYS 10.0 to build the flywheel clutch cover model. The surface heat transfer coefficient is used to replace the heat transfer capacity, and the convection coefficients under natural convection and forced convection in finite space are calculated respectively. Two steps of load are set to generate heat first and then cool it. Compared with the results of the two convection coefficient charts, the cooling effect of forced ventilation is obviously better than that of natural convection. In a short time, the forced ventilation of the retarder can be braked again. Therefore, it is necessary to open the ventilation and heat dissipation of the engine eddy current retarder. Qiu Xuyun's work shows that using commercial software such as Ansys can effectively optimize the design of thermodynamics and hydrodynamics, making it another powerful method for structural optimization design.

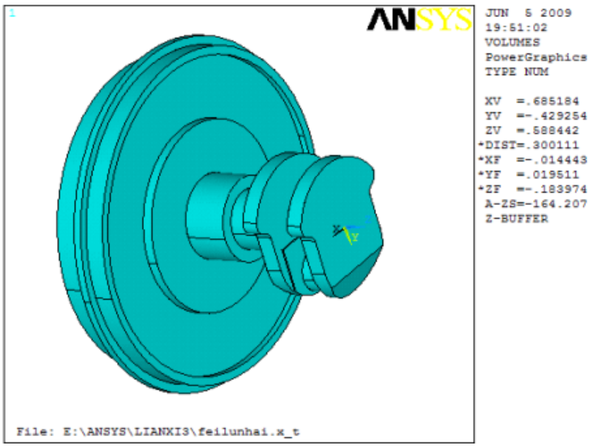

Figure 4. The Finite Element of Totor And Clutch Shell

3.6. Numerical Simulation of Brake Torque Characteristic Analysis

In 2018, Ye Lezhi et al. [19] proposed a permanent magnet eddy current retarder with stepless adjustment of braking torque based on the principle of permanent magnet eddy current braking to solve the problem of excessive braking load of heavy haul trucks downhill, which is used for vehicle auxiliary braking. The suction characteristics of permanent disk and vortex disk are analyzed by finite element method, and the brake torque adjusting mechanism is designed. By establishing the numerical analysis model of the permanent magnet eddy current retarder, the electromagnetic field distribution of the retarder is analyzed by using the finite element simulation software JMAG Designer, and the relationship between the braking torque and the speed change is obtained. By analyzing the influence of temperature on the electromagnetic characteristics of the vortex disc material, the law of brake torque changing with temperature is obtained by numerical simulation Trial production Φ 485mm × The 255 mm permanent magnet eddy current retarder prototype was compared with the numerical simulation data and test data of different air gaps, and the braking characteristics of the retarder with different eddy current disc materials were tested on the bench. The results show that the numerical simulation at low speed is in good agreement with the bench test data.

4. Summary

The research and application of numerical analysis based on finite element method in eddy current retarder has been 24 years since Norio Takahashi, a Japanese scholar, started in 1998. With the continuous development of computer technology and software technology, the technical means and application scope of numerical analysis have been different. A wide variety of CAE software provides a tool for the research of eddy current retarder, and CAE software has gradually been accepted by more engineers, in which product simulation, analysis and optimization are carried out. With the development of cloud computing, the use of computers is undergoing tremendous changes. The obstacles to computing power will gradually disappear in the foreseeable future. The intelligence and automation of analysis and optimization will enter the AI level. The analysis and design of eddy current retarder must follow this step in order to obtain considerable development.

Acknowledgment

This paper was supported by the project of science and technology research program of Chongqing Education Commission of China. (No. KJQN202203210).

References

[1] Dumbaugh E, Saha D. The traffic safety impacts of introducing transit service on urban freight corridors: A comparative examination of the Orlando SunRail and Charlotte Lynx systems [J]. Case Studies on Transport Policy, 2021, 9(3): 1399-406.

[2] Eitrheim M H R, Log M M, Torset T, et al. Opportunities and Barriers for Truck Platooning on Norwegian Rural Freight Routes [J]. Transportation Research Record, 2022, 2676(6): 810-24.

[3] Talukder M A S, Tedla E G, Hainen A M, et al. Analytical and Empirical Evaluation of Freight Priority System in Connected Vehicle Environment [J]. Journal of Transportation Engineering Part a-Systems, 2022, 148(6):

[4] Ergun R E, Ucar M, Ertunc H M, et al. A development of electromagnetic retarder controller to stabilise vehicle speed by using PWM technique [J]. International Journal of Heavy Vehicle Systems, 2014, 21(2): 169-81.

[5] Reed J. Electric retarders [M]. 1973.

[6] Busher V, Horoshko V, Shestaka A, et al. Fractional Integrated Dual Electromagnetic Retarder Controller for Tuning Internal Combustion Engines [M]. 2020.

[7] Yan Q-d, Zou B, Wei W. Numerical investigation of hydrodynamic tractor-retarder assembly under traction work condition [J]. Journal of Beijing Institute of Technology, 2011, 20(4): 472-7.

[8] Nayak P, Armani A. Optimal Design of Functionally Graded Parts [J]. Metals, 2022, 12(8):

[9] Liu W K, Li S, Park H S. Eighty Years of the Finite Element Method: Birth, Evolution, and Future [J]. Archives of Computational Methods in Engineering, 2022.

[10] Khalesidoost S, Faiz J, Mazaheri-Tehrani E. An overview of thermal modelling techniques for permanent magnet machines [J]. Iet Science Measurement & Technology, 2022, 16(4): 219-41.

[11] Muzel S D, Bonhin E P, Guimaraes N M, et al. Application of the Finite Element Method in the Analysis of Composite Materials: A Review [J]. Polymers, 2020, 12(4):

[12] Marinkovic D, Zehn M. Survey of Finite Element Method-Based Real-Time Simulations [J]. Applied Sciences-Basel, 2019, 9(14):

[13] Takahashi N, Natsumeda M, Muramatsu K, et al. Optimization of permanent magnet type of retarder using 3-D finite element method and direct search method [J]. Ieee Transactions on Magnetics, 1998, 34(5): 2996-9.

[14] Canova A, Freschi F, Repetto M, et al. Eddy current coupler optimization; proceedings of the Second International Conference on Power Electronics, Machines and Drives (PEMD 2004), F 31 March-2 April 2004, 2004 [C].

[15] Niu R-X, He R. Robust design technique for permanent magnet type retarder [J]. Jiangsu Daxue Xuebao (Ziran Kexue Ban) / Journal of Jiangsu University (Natural Science Edition), 2006, 27(6): 493-6.

[16] Xiaobo Z, Changying J, Yiqi H, et al. Research on Electromagnetic Field and Braking Torque for Permanent Magnet Type Eddy Current Retarder Based on Rogowski Method [J]. Transactions of the Chinese Society of Agricultural Machinery, 2009, 40(1): 35-9+14.

[17] Bingfeng J, Desheng L, Yunkang S, et al. Structure optimization for magnetic equipment of permanent magnet retarder [J]. Frontiers of Mechanical Engineering in China, 2010, 5(4): 442-5.

[18] Qiu X-y, Yu M-j, Yi F-y. Cooling Finite Element Analysis of Engine Eddy Current Retarder [M]. 2010.

[19] Ye L, Liu Y, Cao M, et al. Braking Characteristics and Experiment of a Permanent Magnet Eddy-current Retarder [J]. J Beijing Univ Technol (China), 2018, 44(6): 837-42.