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Research of the L-Type Gantry Crane's System Based on BP Network and Genetic Algorithm

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Abstract: A kind of parametric finite element analysis system for the L type gantry crane's gate frame is developed by making use of the secondary development on the platform of ANSYS, MATLAB through VC++ programming. The interface technology of VC++, ANSYS, and MATLAB is employed as well as the encapsulation on APDL. To input parameter in the VC++ and to calculate the quality of the L type gantry crane so as to obtain the network training specimens constituted with 20 sets of parameters. The BP network is used to establish the mapping relationship which provides the adaptability function for the genetic algorithm. The genetic algorithm is adopted to accomplish the quality optimization. Then the ANSYS software is employed to simulate the optimized L type gantry crane. The results of the optimization and simulation show that the overall performance of the L type gantry crane is improved dramatically. *Copyright © 2013 IFSA.*

Keywords: L Type gantry crane, Parametric, Finite element method, BP network, Genetic algorithm, Visual C++.

1. Introduction

Gantry crane is widely used in outdoor places such as ports, stations and construction sites [1]. With the rapid development of the economy and trade of our country, crane machines become more effective and bigger.

This will inevitably lead to continuous increase of the size, load and weight of the crane whose performance directly affects its working efficiency [2].

Therefore, based on the object-oriented technology, this paper first uses neural network mapping and the genetic algorithm optimization methods to optimize the main parameters that influence the mechanical properties of gantry crane. Then ANSYS is utilized for parametric modeling. Finally, the calculation results are analyzed to check whether the obtained parameters meet the requirements of strength, stiffness and stability.

2. Setting up Optimized Mathematical Model of L Type Gantry Crane Structure

2.1. Design Variables of Gantry Crane

During the optimization design of L type gantry crane, in order to make the performance indexes of the structure meet the requirements and to minimize its quality, the number of design parameters is large. Moreover, to improve the design efficiency, parameters which greatly influence the structure analysis are also selected as design variables. Fig. 1 shows the interface for the editing of optimized parameters. There are 16 selected design variables of gantry crane including: upper cover plate width of main girder X1 (initial value is 930); lower cover plate width of main girder X2 (initial value is 930); web height of main girder X3 (initial value is 1500); upper cross section height of outrigger X17 (initial value is 950); upper cross section width of outrigger X18 (initial value is 1520); lower cross section width of outrigger X19 (initial value is 450); lower cross section height of outrigger X20 (initial value is 350); section height of bottom girder X13 (initial value is 600); section width of bottom girder X14 (initial value is 450); cover plate thickness of main girder X4 (initial value is 10); main web thickness of main girder X5 (initial value is 12); vice web thickness of main girder X6 (initial value is 8); cover plate thickness of outrigger X11 (initial value is 8); web thickness of outrigger X12 (initial value is 10); cover plate thickness of bottom girder X15 (initial value is 10); web thickness of bottom girder X16 (initial value is 12). These design variables and the span, outrigger height, cantilever length and cart wheel track as well as some other important sizes basically determine the overall performance and quality of the L type gantry crane.

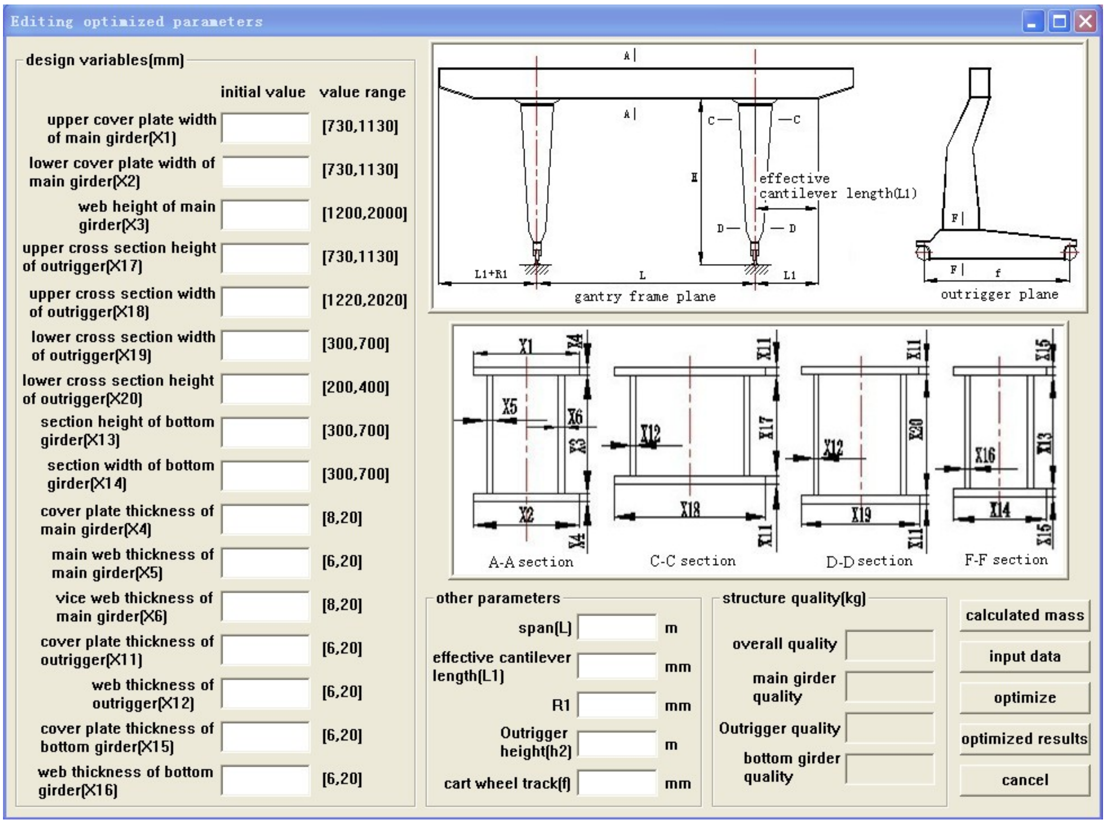

Fig. 1. Interface of editing optimized parameters.

2.2. Objective Function

The minimum quality of the L type gantry crane structure is calculated by the design objective function $f(x)$ on the basis of meeting the overall performance and system reliability requirements. It is described as:

$$f(x) = f(x1) + f(x2) + f(x3), \tag{1}$$

where $f(x1)$ is the quality of the main girder; $f(x2)$ is the total quality of the outriggers; $f(x3)$ is the total quality of the bottom girders; but the qualities of the wheels and rails are not contained in $f(x)$.

2.3. Constraint Conditions

The establishment of the constraint conditions should fully meet the requirements of strength, stiffness, stability and process size etc. There are two main constraints: performance constraints and geometry constraints. For L type gantry crane, the main constraints are: the maximum static stiffness with main girder span in the middle and span at the end; the maximum static strength with main girder span in the middle and span at the end; the maximum normal stress with span in the middle and cantilever at the end; the maximum shear stress with span in the middle of web and cantilever at the end root; the biggest stress at the joint with cantilever at the end root of web and cover plate; the maximum stress at the joint with span in the middle of main web and the upper cover plate; the outrigger variable cross-section strength in the gantry frame plane and outrigger plane; the maximum normal stress at the bottom of the girder; the portal frame dynamic stiffness. In addition, aspect ratio of box section, moment of inertia ratio of outrigger related section, width-to-thickness ratio of board and the upper and lower bounds of the design variables, etc. should be considered.

3. Determining the Number of Specimens

Training specimens are vital for the establishment of the neural network. Only when the number and distribution of training specimens are reasonable can they correctly reflect the mapping relationship of the network model. Using orthogonal test method to determine the number of specimens can get sample points which are comprehensive and distributed evenly with less specimens [3].

In this study, the determination of the number of training specimens of neural network model of gantry crane structure makes use of the orthogonal table $L_{20}(2^{19})$, that is to say, the total number of specimens is 20 and the number of factors (design variables) is no more than 19. This design includes 16 factors and each factor has 2 levels. The Orthogonal test factors and their distribution are shown in table 1. For all the twenty specimens, VC++ programming is used to calculate the corresponding quality of the L type gantry crane for each specimens group and the calculation results are regarded as the output variables of the neural network model. Table 2 lists the related parameters of the specimens.

Table 1. Orthogonal test factors and their distribution table.

Factor level	**Upper cover plate width of main girder X1/mm**	**Lower cover plate width of main girder X2/mm**	**Web height of main girder X3/mm**	**Upper cross section height of outrigger X17/mm**	**Upper cross section width of outrigger X18/mm**	**Lower cross section width of outrigger X19/mm**	**Lower cross section height of outrigger X20/mm**	**Section height of bottom girder X13/mm**
1	930	830	1500	950	1520	450	250	450
2	1030	930	1800	1050	1820	600	350	600
Factor level	**Section width of bottom girder X14/mm**	**Cover plate thickness of main girder X4/mm**	**Main web thickness of main girder X5/mm**	**Vice web thickness of main girder X6/mm**	**Cover plate thickness of outrigger X11/mm**	**Web thickness of outrigger X12/mm**	**Cover plate thickness of bottom girder X15/mm**	**Web thickness of bottom girder X16/mm**
1	450	8	10	8	8	8	8	10
2	600	10	12	10	10	10	10	12

Table 2. Data of specimens.

Test number	**X1**	**X2**	**X3**	**X17**	**X18**	**X19**	**X20**	**X13**	**X14**	**X4**	**X5**	**X6**	**X11**	**X12**	**X15**	**X16**	**Self weight (kg)**
1	1030	830	1800	950	1520	450	250	600	600	8	12	10	8	8	10	12	14502.5
2	1030	930	1500	950	1820	600	350	600	450	10	10	10	8	8	8	10	15352.7
3	1030	830	1500	950	1520	600	350	450	600	10	10	8	10	10	10	12	15083.3
:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
20	930	930	1800	950	1520	600	350	600	600	8	12	8	10	8	8	10	14246.3

4. BP Network Modeling

The BP neural network is a kind of multilayer feedforward neural network. It can deal with nonlinear information by increasing back spread error signals on the basis of multilayer perception [13]. The standard BP neural network uses the algorithm of gradient descent and chooses Sigmoid function which is continuous and derivable. It is mainly used for system model identification, prediction, data compression and approximation of function etc.

4.1. Setting up BP Network Model

The structure of BP neural network is simple and has a strong nonlinear mapping ability. It is mainly composed by the input layer, the hidden layer (middle layer) and the output layer. Input signals are first sent to the input layer and then transferred to the hidden layer through weighted processing. The transfer function used by the hidden layer is tansig function. After weighting and threshold value processing, the signals from the hidden layer are then transferred to the output layer. The transfer function used by the output layer is purelin function. The general form of the transfer function between different layers is:

$$f(x) = 1/(1 + e^{-\lambda x}), \qquad (2)$$

where x is the input from the previous neurons that has been weighted and threshold value processed; $f(x)$ is the output of the current neuron and also the input of the next panel point.

The 16 factors got by the orthogonal test method are regarded as the input parameters of the neural network; while the quality of L type gantry crane calculated by the parametric interface shown in Fig. 1 is considered as the output parameters of network. A BP neural network simulated model is then established which is composed by the input layer with 16 nodes, the hidden layer with 13 nodes and the output layer with 1 nodes.

4.2. Training BP Network Model

The MATLAB neural network toolbox is called by the VC++ program to train the BP network model in the background and the 20 specimens got by the orthogonal test is implied during this process. Besides, 5 specimens are selected for the testing of the modal. The input and output data is normalized at the beginning of the training. The optimized L-M algorithm is used since it has the fastest convergence speed and lower memory space as compared with other momentum algorithms. Moreover, it can be easily achieved with the trainlm function provided by MATLAB tools. To obtain the learning efficiency of 0.05, the number of training is taken as 1000 and the performance target is taken as 1e-10, and the sim function of toolbox is called as the test function. The training results of the network are shown in Fig. 2. It is found that all the errors are controlled within 1 %, which implies that the establishment of the BP network model is successful.

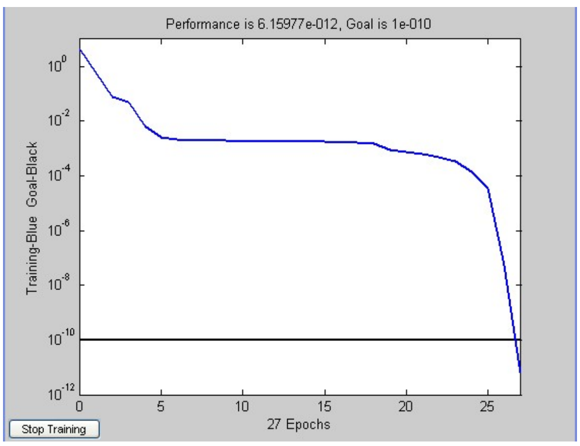

Fig. 2. Results of network training.

5. Optimization of Genetic Algorithm

Genetic algorithm can map implicit functions such as neural network. The advantages of genetic algorithm such as simple calculation, strong robustness, randomness, wholeness and being suitable for parallel processing are used to obtain the best network form and the best weights [4, 14-15].

The genetic algorithm is used to optimize the neural network model and the algorithm toolbox GATBX is employed to carry out optimized calculation. The objective function is described as:

$$ObjV = sim(net, (bs2rv(Chrom, FieldD))')', \qquad (3)$$

where sim is the simulated function of neural network; net is trained neural network model; $bs2rv$ is the transferable function which transforms binary string to real value [5, 9-11]. Since the optimization of the L type gantry crane is aimed to get the minimum quality, the fitness function should be $FitnV = ranking(ObjV)$. The optimized flow chart of the L type gantry crane structure is shown in Fig. 3.

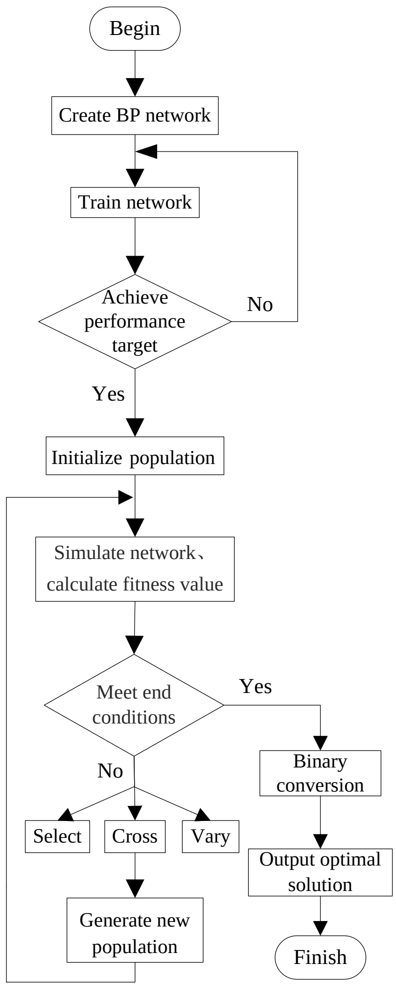

Fig. 3. Optimized flow chart of the L type gantry crane structure.

The design variables are compiled as binary code; the number of population individuals is 40; the largest genetic algebra is 200; the generation gap is 0.9 and the crossover probability is 0.7. Meanwhile, the obtained optimal value and the corresponding design variables need to be converted to the actual value by the counter normalization. Use VC++ calling MATLAB to optimize in the background. The changes of optimal value of the objective function for the first 200 iterations are shown in Fig. 4. After 180 iterations, the objective function almost achieves the optimal value.

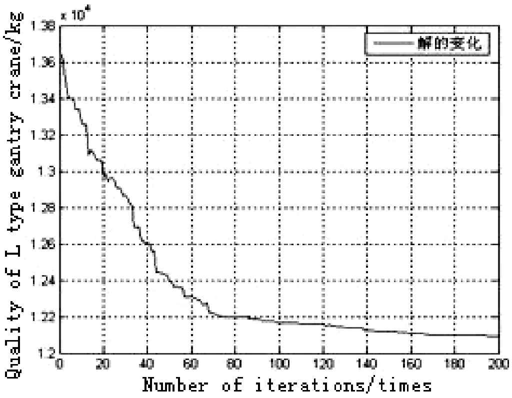

Fig. 4. Changes of optimal value of objective function during 200 times iterations.

The comparison between the optimal design got by the genetic algorithm optimizing and the initial design is shown in Table 3 which demonstrates that the quality of L type gantry crane is reduced by 14.7 % after the optimization design.

6. Finite Element Simulation of Type L Gantry Crane

6.1. Setting up Finite Element Model

After getting the optimal quality of the L type gantry crane, whether its strength and stiffness can meet the requirements should be further considered. The parametric design language APDL of ANSYS is used to construct the parametric model for the L type gantry crane's portal frame; VC++ program is used to compile the graphical user interface and the interface module of VC++ is called to nest VC++ and APDL command stream [6-8]. In order to establish an efficient analysis platform, the APDL macro file encapsulated by VC++ is used to transfer the information [12]. The dialogs are used as human-computer interaction interfaces to set up operation interface for the finite element analysis platform of the L type gantry crane's portal frame.

Table 3. Comparison between initial design and optimal design.

Design	X1	X2	X3	X17	X18	X19	X20	X13	X14	X4	X5	X6	X11	X12	X15	X16	Self weight (kg)
Initial	930	930	1500	950	1520	450	350	600	450	10	12	8	8	10	10	12	14262.2
Optimal	931.6	830	1500.3	951.4	1524.1	451.5	262.6	454.8	450.8	8	10.1	8	8	8	8.1	10	12156.3

Taking the gantry structure analysis of the MGD (L) type single main girder gantry crane (10 t×22 m) of a mechanical co., LTD. as an example, the lifting height is 10m; the lifting speed is 9 m/min; the running speed of the trolley is 35 m/min; the running speed of the cart for 30 m/min; the material is Q235; the safety factor is 1.33 and the working class is A5. After dividing the gantry structure into portal frame plane and outrigger plane, loads are applied on them separately for the simplicity of calculation. Several factors lie in the outrigger plane should be taken into consideration when the cart is breaking, including: the uniformly distributed loads which are caused by the main girder, the outriggers and the self weight of bottom girders; the inertia forces which are caused by the main girder, outriggers, bottom girders, goods and the self weight of the trolley. At the same time, the wind loads which act on the main girder, outriggers, bottom girders, goods and the trolley should also be considered as well as the crane travel mechanism, the cab, the self weight of trolley and the lifting capacity etc. Similarly, most of the above listed factors should also be considered in the portal frame plane when the trolley is braking.

6.2. Analyzing the Results

Through statics analysis the deformation and stress distribution of the L type gantry crane in outrigger plane is obtained. The static rigidity and Von Mises stress distribution of the L type gantry crane are shown in Fig. 5 and Fig. 6 respectively.

Based on the system modeling, we got the maximum stress of the main girder dangerous section is calculated as 143.8 MPa; the static stiffness of the gantry frame is 11.2 mm. In other words,

$$\sigma = 143.8MPa < [\sigma] = 176.69MPa \ ,$$

$$f_j = 11.2mm < \frac{22000}{1000} = 22mm \ ;$$

the strength and stiffness meets the requirements.

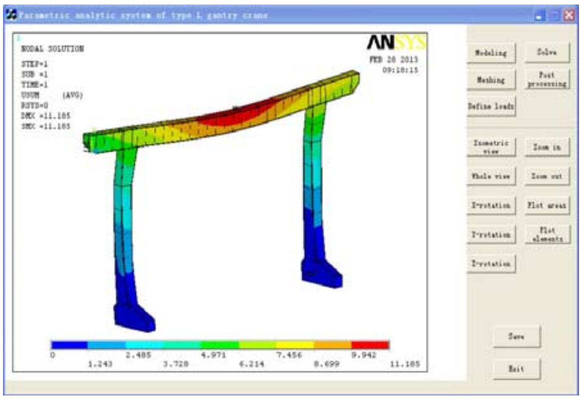

Fig. 5. Result of static rigidity.

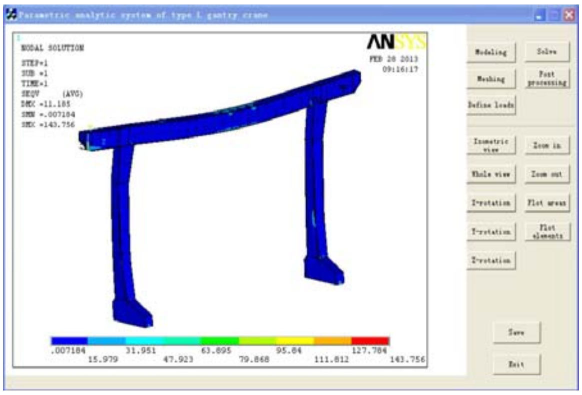

Fig. 6. Result of Von Mises stress.

7. Conclusions

A kind of parametric finite element analysis system for the L type gantry crane is developed by making use of secondary development on the ANSYS and MATLAB software by VC++ programming, and by combining finite element method, BP neural network and genetic algorithm organically. First of all, the design variables and the overall quality calculated by VC++ are selected as the training specimens for the neural network; then the BP neural network model of the L type gantry crane is set up; afterwards, the genetic algorithm is employed to complete the parameter optimization and to analyze the optimal solution by using finite element methods; finally, the optimal solution is tested to meet the requirements of strength and stiffness. The optimized overall quality of the L type gantry crane has decreased by 14.7 % as compared to the quality before the gantry crane is optimized, and its overall performance is obviously improved. This system realizes the visualization of the whole analysis process. Thus, it's possible for the technicians to finish the whole analysis process correctly under the guidance of the dialogs. Moreover, the correctness of the parameters becomes convenient. The operating system can improve the speed of product analysis and shorten the product development cycle. Technicians who are not familiar with the ANSYS software and finite element analysis technology can also use this system easily.

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