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Structural Optimization of Rolling Shear Based on Agent Model of Radial Basis Function

Yugui Li and Yantao Chu

Taiyuan University of Science and Technology, Heavy Machinery of Engineering Research Center of Ministry of Education, Taiyuan 030024, China
liyugui2008@163.com; chuyantao2013@163.com

Abstract

To solve the problems of the uneven overlap quantity and the horizontal displacement of the upper blade during the cutting process, an optimization method based on the agent model of radial basis function was proposed. Through uniform design, rational experimental samples were selected and the agent model of rolling shear based on radial basis function was established, then the model was optimized by using genetic algorithm (GA). The optimal solution shows that the optimized synthetic horizontal displacement of the midpoints (mean value of all horizontal displacement relating to calculated points) reduced by 50.8% and the amount of overlap of the upper blade fluctuation reduced by 70.15%. Applications have proved this method is suitable for structural optimization of rolling shear.

Keywords*: rolling shear, uniform design, radial basis function, structural optimization*

1. Introduction

Rolling shear with a double shaft and double eccentricity has been widely used in plate production line and has become key equipment in steel plate finishing line. Compared with the traditional beveled shear machine, it has the characteristics of higher shear quality, easier maintenance and more efficiency. Compared with the hydraulic rolling shear, it has the advantage of simpler structure, lower cost, and simpler control system [1].

The world's first rolling shear was successfully developed by the company of Monaco Newman in Germany, and then it was mastered by Japan, Russia and Australia *etc.* [2]. In China, it was studied by many institutions. A design method of double-freedom rolling shear mechanism size, which was based on the mechanism centrode, was proposed by Yali Ma and Kangkang Li in Dalian University of Technology, and the mathematical model of the rolling shear mechanism for optimization design was built, in which the error between instantaneous center of the shear blade was used as the objective function [3].The optimized mathematical model of shear mechanism with guide rod as additional design was established by Qingxue Huang and Lifeng Ma in Taiyuan University of Science and Technology. The parametric model of the shear mechanism was established by Huixin Yang and Xiaoqiang Sun, through which the trajectories of the referenced points were got, and the parameters were optimized to get closer to the pure shearing [4-7]. However, absolutely pure rolling cut is difficult to achieve [8], another method to solve this problem should be developed.

In this paper, a new method, which was based on uniform design and radial basis function, was proposed. The difference between the actual trajectory and the theoretical trajectory of the midpoint in the cutting edge was regarded as the objective function. The related parameters which influence the overlap quantity as well as the horizontal displacement of the upper blade were selected to construct the design variables in the uniform design table, and then the agent model based on the radial basis function was built. After that genetic algorithm (GA) was applied to optimize the model, and the best

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parameter combination was obtained. The optimal solution shows that the optimized synthetic horizontal displacement of the midpoints (mean value of all horizontal displacement relating to calculated points) reduced by 50.8%, and the amount of overlap of the upper blade fluctuation reduced by 70.15%.

2. Uniform Design

Uniform design, proposed by professor Fang and Yang in 1990s, is an efficient experimental design method. As a space filling design, it has been widely applied in manufacturing, system engineering, pharmaceutics, and natural sciences [9-10]. Number theory and multivariate statistics are applied to the design of experiment, which is suitable for solving the problem of "computer simulation" and "model of the unknown and random error design"[11]. The main idea of the uniform design is to scatter its design points on the experimental domain under some uniformity measures. Design points are uniformly dispersed in a high-dimensional space, so that the limited data have broad representation, which can effectively avoid the expensive computational cost.

Like orthogonal design, uniform design offers lots of experimental tables for users to conveniently utilize. Uniform design table is generally denoted as $U_n(n^m)$, where n represents the number of rows and that is also the number of experiment runs; m refers to the number of columns of the table, which must be greater than or equal to the number of factors. The example is shown in Table 1. $U_6(6^4)$ means that there are 4 variables, and each variable has 6 levels. If there are two variables, the second row in Table 2 was used to pick up the samples.

Table 1. $U_6(6^4)$

	1	2	3	4
1	1	2	3	6
2	2	4	6	5
3	3	6	2	4
4	4	1	5	3
5	5	3	1	2
6	6	5	4	1

Table 2. Selection Scheme of $U_6(6^4)$

N	Numerical order	D
2	1 3	0.1875
3	1 2 3	0.2656
4	1 2 3 4	0.2990

Where N is the number of variables; D is the discrepancy of uniformity.

3. The Agent Model of Radial Basis Function

3.1. Radial Basis Function

Radial basis function (RBF) was first proposed by Rolland Hardy to fit the irregular topographic contours of geographical data [12]. The main idea of radial basis function is to find a $f(x)$, whose value is approximately equal to the real-valued function $F(x)$ [13]. The basic form of the radial basis function is

$$\mathrm{F}(x) \approx f(x) = \sum_{i=1}^{m} \beta_i \phi(r_i, \mathrm{c}) \tag{1}$$

Where $\beta = [\beta_1, \beta_2 \cdots, \beta_m]^T$ is Weighting coefficients; $\phi = [\phi(r_1, c), \phi(r_2, c), \cdots, \phi(r_m, c)]^T$ is the basic function; m is the number of collocation points; $r_i = \|x - x_i\|$ is the distance between x and x_i in space; $\|\cdot\|$ is called Euclidean norm; $\phi(\cdot)$ is a suitably chosen radial basis function; and c is a user-defined constant which is usually required to be non-negative. Since under normal circumstances, any function can be represented as a weighted sum of a set of basis functions, and a nonlinear mapping which expresses the relationship between factors and response can be achieved[14].Several classes of radial basis functions can be chosen for $\phi(\cdot)$, such as Thin-Plate Spline, Multiquadric, Reciprocal, and Gaussian *etc.* [15].

The agent model based on radial basis function can be expressed as

$$f(x) = \sum_{i=1}^{m} \beta_i \phi(\|x - x_i\|) \tag{2}$$

As the agent model, $f(x)$ should meet the requirement

$$f(x) = F(x_j) \quad (j = 1, 2 \cdots m, \tag{3}$$

Let $r_{ij} = \|x_i - x_j\|$, equation can be obtained

$$A \cdot \beta = F \tag{4}$$

Where $A = \begin{bmatrix} \phi(\|x_1 - x_1\|) & \cdots & \phi(r\|x_1 - x_m\|) \\ \vdots & \ddots & \vdots \\ \phi(\|x_m - x_1\|) & \cdots & \phi(\|x_m - x_m\|) \end{bmatrix}, \beta = \begin{bmatrix} \beta_1 \\ \vdots \\ \beta_m \end{bmatrix}, F = \begin{bmatrix} F(x_1) \\ \vdots \\ F(x_m) \end{bmatrix}$,with

solving this linear system, the weighting coefficients β ($\beta = A^{-1} \cdot F$)can be computed.

3.2. The Accuracy Assessment of Agent Model

The accuracy assessment is essential to the agent model, which decides whether the model can be used for further optimization. The commonly used approximate model assessment measures are as follows [16~17]:

(1).The root mean square error (RMSE) is

$$RMSE = \frac{1}{k\bar{y}} \sqrt{\sum_{i=1}^{k} (y_i - \hat{y}_i)^2} \tag{5}$$

(2).The coefficient of determination (R^2) is

$$R^2 = \frac{\sum_{i=1}^{k} (\hat{y}_i - \bar{y}_i)^2}{\sum_{i=1}^{k} (y_i - \bar{y}_i)^2} \tag{6}$$

Where k is the number of samples; y_i is the real response; $\hat{y}_i$ is the responses which are obtained from the agent model; $\bar{y}$ is the average of the real responses. The smaller the value of RMSE, the more accurate the agent model is, as for R^2 , the closer to 1, the more accurate the agent model is.

4. Structural Analysis and the Establishment of the Objective Function

4.1. The Analysis of Rolling Shear

As shown in Figure 1, rolling shear with a double shaft and double eccentricity consists of two cranks, two connecting rods, one guide rod and two blades. There is a fixed phase difference between two cranks, but they have the same angular velocity. The whole cutting process can be divided into three stages: start cutting, rolling cutting, and the end of the cut. The upper blade will achieve rolling shear due to the phase difference of two cranks and the guiding role of the guide rod.

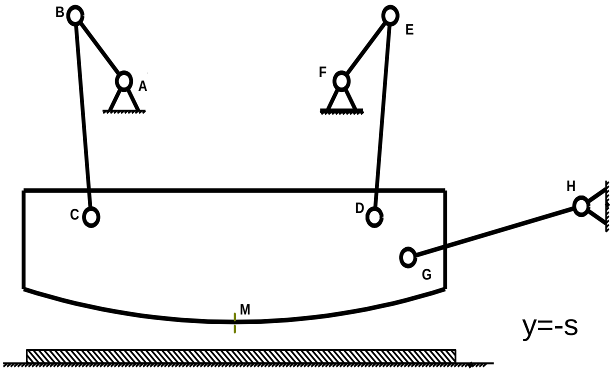

Figure 1. Simplified Diagram of Rolling Shear Mechanism

Formula of degrees of freedom is as follows:

$$F = 3n - (2P_l + P_h) \tag{7}$$

Where n is the number of moving links; P_l is the lower pair, P_h is the higher pair. As shown in Figure 1, the parameters of them are $n = 6,\ p_l = 8,\ p_h = 0$; the value of F is 2 according to the equation (7). The number of independent input motions is equal to the degrees of freedom, so the mechanism has a prescribed motion.

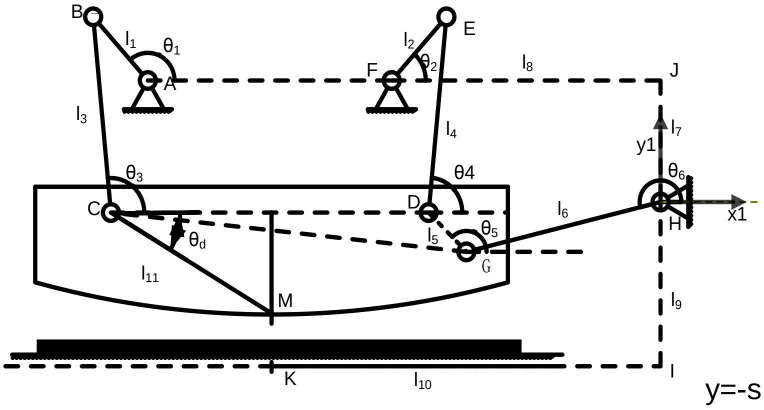

Figure 2. Kinematic Diagram of Mechanism

As shown in Figure 2, a fixed coordinate system x_1Hy_1 is established. The initial position relationship of the two cranks is $\theta_1 + \theta_2 = 180^\circ$. Meanwhile there is a fixed phase difference between θ_1 and θ_2 during the cutting process.

4.2. Theoretical Trajectory of the Upper Blade

The theoretical trajectory is the curve when the upper blade achieves pure rolling without considering cranks, connecting rod and guide rod. As shown in Figure 3.

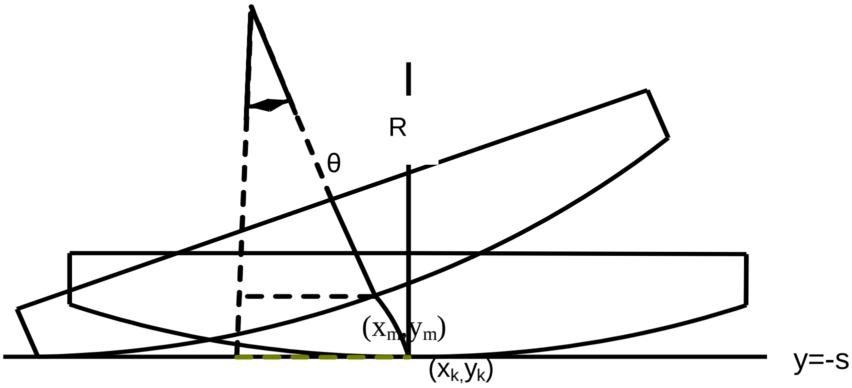

Figure 3. Theoretical Trajectory of Midpoint

The function can be expressed as:

$$\begin{aligned} x_m &= -R\cdot\theta + R\sin\theta - x_k \\ y_m &= R - R\cos\theta - y_k \end{aligned} \tag{8}$$

Where (x_m, y_m) is the point of theoretical trajectory; R is the radial of the arc of the upper blade; θ is the turning angle; (x_k, y_k) is the position of the point in the standard line which is corresponding to the midpoint of the upper blade in the fixed coordinate system x_1Hy_1.

4.3. Actual Trajectory of the Upper Blade

The actual trajectory is the real curve considering cranks, connecting and guide rods. As shown in Figure 2.The function can be expressed as follows:

$$\begin{aligned} x_{mm} &= l_1\cos\theta_1 - l_3\cos\theta_3 + l_{11}\cos(\theta_d - \theta) - x_A \\ y_{mm} &= l_1\sin\theta_1 - l_3\sin\theta_3 - l_{11}\sin(\theta_d - \theta) + y_A \end{aligned} \tag{9}$$

Where (x_{mm}, y_{mm}) is the point of actual trajectory; l_1 is the length of AB, l_3 is the length of BC, l_{11} is the length of CM, θ_d is a fixed angle, θ is the turning angle, x_A, y_A is the position of A in the fixed coordinate system x_1Hy_1 .As for the correspondence relationship between θ_1 and θ_3, the closed vector polygons can be used to work it out. The vector polygons are as follows: ABCGHJFA and FEDGHJF. The closed position vector equations can be expressed as:

$$\begin{aligned} a_1 &= L_1\cos\theta_1 - L_3\cos\theta_3 - CG\cos(\theta_5 + \angle CGD) - L_6\cos\theta_6 - L_8 - AJ \\ a_2 &= L_1\sin\theta_1 - L_3\sin\theta_3 - CG\sin(\theta_5 + \angle CGD) - L_6\sin\theta_6 + L_7 \\ a_3 &= -L_2\cos\theta_2 + L_4\cos\theta_4 + L_5\cos\theta_5 + L_6\cos\theta_6 + L_8 \\ a_4 &= -L_2\sin\theta_2 + L_4\sin\theta_4 + L_5\sin\theta_5 + L_6\sin\theta_6 - L_7 \end{aligned} \tag{10}$$

Where the length of all links is known; the initial value of θ_5 can be calculated out; θ_1 and θ_2 have fixed phase difference. Using $F = |a_1| + |a_2| + |a_3| + |a_4|$ as the objective function, genetic algorithm (GA) is applied for the optimization.

4.4. The Establishment of Objective Function

The main purpose of the optimization is to make the actual trajectory of the midpoint closer to the theoretical trajectory, that is, the deviation between them is minimum. The expression of the objective function is

$$F(X) = \frac{1}{n}\sum_{i=1}^{n}\sqrt{(x_m - x_{mm})^2 + (y_m - y_{mm})^2} \tag{11}$$

4.5. The Constraints

$$\begin{aligned} g_1(x) &= l - l_1 - l_2 + l_2\sqrt{1-(\frac{l_1}{l_2})^2\cos^2\theta_1} - l_1\sin\theta_1 \le 0 \\ g_2(x) &= -l_5 - l_6 + l_8 < 0 \\ g_3(x) &= \sqrt{[l_1\cos(270-\theta_1) + \sqrt{l_1^2\cos^2(270-\theta_1) - l_1^2 + l_2^2} - l_7]^2 + l_7^2} - l_5 - l_6 < 0 \end{aligned} \tag{12}$$

Where $g_1(x)$ is the constraint of maximum opening degree, l is the sum of maximum opening degree and overlap quantity. $g_2(x)$ and $g_3(x)$ are the constraints of geometric, which guarantee that three lines constitute a triangle.

The steps of structural optimization, which are based on the radial basis function, are as follows:

(1). According to the goal of achieving pure rolling cut, setting the upper blade rolling on the line y=-s, x_k, y_k is taken on the line, and then the theoretical trajectory of the midpoint of the upper blade can be worked out through equation (8). Since it is a nonlinear system, the trajectory is represented by a series of points (x_m, y_m), which are corresponding to different turning angles. Meanwhile, the actual trajectory can be obtained through equation (9), which is also represented by a series of points (x_{mm}, y_{mm}).

(2).According to the corresponding (x_m, y_m) and (x_{mm}, y_{mm}), the objective function value can be worked out through equation (11).

(3).Establish uniform design based on factors, meanwhile, repeat the steps (1) and (2), and calculate out the objective function values, then fill them in the uniform design table.

(4). Establish the agent model based on the radial basis function according to the uniform design table.

(5) In order to evaluate the accuracy of the model, conduct an accuracy assessment of the agent model based on the equation (5) and equation (6).

(6) After all of above, the best parameter combination can be obtained by using genetic algorithm (GA).

5. Numerical Result

The basic processing parameters are shown in Table 3.

Table 3. The Basic Processing Parameters

thickness (mm)	width (mm)	open degree (mm)	overlap (mm)
6~50	1500~3500	200	5

According to the principles analysis of shear mechanism and the target that achieves pure rolling cut, $l_1, l_3, l_5, l_6, l_7, l_8, \theta_1$ were selected as the design variables:

$$x = [x_1 \ \ x_2 \ \ x_3 \ \ x_4 \ \ x_5 \ \ x_6 \ \ x_7]^T = [l_1 \ l_3 \ l_5 \ l_6 \ l_7 \ l_8 \ \theta_1]^T$$

Where $x_1 \in [100,136]$, $x_2 \in [700,925]$, $x_3 \in [800,1052]$, $x_4 \in [800,1052]$, $x_5 \in [900,1116]$ $x_6 \in [1300,1660]$, $x_7 \in [100,136]$

5.1. Uniform Experimental Design

Since this design has seven variables, in order to obtain an accurate optimization result, the table of $U_{37}(37^{12})$ was selected; every variable has 37 levels, which means to calculate for 37 times. The columns of 1, 2, 3, 4, 6, 9, and 12 were picked up to correspond to seven design variables. Uniform experimental design matrix and response values are given in Table 4.

Table 4. Uniform Experimental Design Matrix and Response Values

Number	Design matrix							F(X)
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	
1	1 (100)	7 (742)	9 (856)	10 (863)	12 (966)	26 (1550)	33 (132)	35.2600
2	2 (101)	14 (791)	18 (919)	20 (933)	24 (1038)	15 (1440)	29 (128)	81.0635
3	3 (102)	21 (840)	27 (982)	30 (1003)	36 (1110)	4 (1330)	25 (124)	125.8900
4	4 (103)	28 (889)	36 (1045)	3 (814)	11 (960)	30 (1590)	21 (120)	123.8768
5	5 (104)	35 (938)	8 (849)	13 (884)	23 (1032)	19 (1480)	17 (116)	93.1391
6	6 (105)	5 (728)	17 (912)	23 (954)	35 (1104)	8 (1370)	13 (112)	86.2357
7	7 (106)	12 (777)	26 (975)	33 (1024)	10 (954)	34 (1630)	9 (108)	94.8816
8	8 (107)	19 (826)	35 (1038)	6 (835)	22 (1026)	23 (1520)	5 (104)	126.8206
9	9 (108)	26 (875)	7 (842)	16 (905)	34 (1098)	12 (1410)	1 (100)	95.8507
10	10 (109)	33 (924)	16 (905)	26 (975)	9 (948)	1 (1300)	34 (133)	153.5950
11	11 (110)	3 (714)	25 (968)	36 (1045)	21 (1020)	27 (1560)	30 (129)	67.7176
12	12 (111)	10 (763)	34 (1031)	9 (856)	33 (1092)	16 (1450)	26 (125)	100.218
13	13 (112)	17 (812)	6 (835)	19 (926)	8 (942)	5 (1340)	22 (121)	117.9939
14	14 (113)	24 (861)	15 (898)	29 (996)	20 (1014)	31 (1600)	18 (117)	95.1761
15	15 (114)	31 (910)	24 (961)	2 (807)	32 (1086)	20 (1490)	14 (113)	114.8042
16	16 (115)	1 (700)	33 (1024)	12 (877)	7 (936)	9 (1380)	10 (109)	156.3762
17	17 (116)	8 (749)	5 (828)	22 (947)	19 (1008)	35 (1640)	6 (105)	42.7748
18	18 (117)	15 (798)	14 (891)	32 (1017)	31 (1080)	24 (1530)	2 (101)	90.6180
19	19 (118)	22 (847)	23 (954)	5 (828)	6 (930)	13 (1420)	35 (134)	128.1527
20	20 (119)	29 (896)	32 (1017)	15 (898)	18 (1002)	2 (1310)	31 (130)	171.6134
21	21 (120)	36 (945)	4 (821)	25 (968)	30 (1074)	28 (1570)	27 (126)	73.7770
22	22 (121)	6 (735)	13 (884)	35 (1038)	5 (924)	17 (1460)	23 (122)	110.0489
23	23 (122)	13 (784)	22 (947)	8 (849)	17 (996)	6 (1350)	19 (118)	140.3047
24	24 (123)	20 (833)	31 (1010)	18 (919)	29 (1068)	32 (1610)	15 (114)	104.7908
25	25 (124)	27 (882)	3 (814)	28 (989)	4 (918)	21 (1500)	11 (110)	125.8078
26	26 (125)	34 (931)	12 (877)	1 (800)	16 (990)	10 (1390)	7 (106)	153.7454
27	27 (126)	4 (721)	21 (940)	11 (870)	28 (1062)	36 (1650)	3 (102)	61.3644
28	28 (127)	11 (770)	30 (1003)	21 (940)	3 (912)	25 (1540)	36 (135)	115.7547

29	29 (128)	18 (819)	2 (807)	31 (1010)	15 (984)	14 (1430)	32 (131)	90.2210
30	30 (129)	25 (868)	11 (870)	4 (821)	27 (1056)	3 (1320)	28 (127)	116.9458
31	31 (130)	32 (917)	20 (933)	14 (891)	2 (906)	29 (1580)	24 (123)	137.7317
32	32 (131)	2 (707)	29 (996)	24 (961)	14 (978)	18 (1470)	20 (119)	127.9471
33	33 (132)	9 (756)	1 (800)	34 (1031)	26 (1050)	7 (1360)	16 (115)	103.5282
34	34 (133)	16 (805)	10 (863)	7 (842)	1 (900)	33 (1620)	12 (111)	97.6450
35	35 (134)	23 (854)	19 (926)	17 (912)	13 (972)	22 (1510)	8 (107)	147.8942
36	36 (135)	30 (903)	28 (989)	27 (982)	25 (1044)	11 (1400)	4 (103)	193.4111
37	37 (136)	37 (952)	37 (1052)	37 (1052)	37 (1116)	37 (1660)	37 (136)	119.1857

5.2. Optimization of the Agent Model

In this paper multiquadric function was selected as the kernel function of radial basis function, and the kernel function is noted as

$$\phi(r) = \sqrt{r^2 + c^2} \tag{13}$$

Where c is a positive shape parameter, here taken $c = 1$, the expression of fitting function is

$$f(x) = \sum_{i=1}^{m} \beta_i \sqrt{r^2 + 1} \tag{14}$$

Weighting coefficient matrix can be obtained according to equation (3), (4) as well as uniform design scheme in Table 4. The expression of radial basis functions can be obtained: $F = A\beta$

β =[0.4591 0.1701 0.3239 0.1034 0.1822 0.0235 0.0187 -0.0798 -0.0421 0.0874 0.2125 0.114 -0.019 -0.0401 0.0206 -0.092 0.0871 -0.1464 0.1782 -0.0133 0.1567 -0.0247 -0.1535 -0.0589 -0.1054 -0.1859 0.01 0.0867 0.1332 0.1151 -0.0183 -0.2009 -0.0669 -0.1275 -0.3925 -0.481 0.0787]^T.

Accuracy assessments of agent model are shown in Table 5, which prove the fitness of the agent model is good, and then the radial basis function is optimized by genetic algorithm. Optimal solution can be calculated out, which is shown in Table 6.

Table 5. Accuracy Assessment of Agent Model

	$F(x)$
RMSE	1.62
R^2	0.9976

Table 6. Main Parameters

variables	original results(mm)	optimized results(mm)
$l_1 = l_2$	115	114
$l_3 = l_4$	865	709
l_5	862	952
l_6	800	892
l_7	988	1064
l_8	1624.6	1646.5
θ_1	117	121

Figure 4 is the overlap amount curves of each testing point before and after optimization. It can be seen from Figure 4 that the blade overlap fluctuate significantly smaller after optimization, which means its overlap is more uniform. The absolute difference between the maximum and minimum values of overlap curves decreases from 6.80 to 2.03, reduced by 70.15%. Figure 5 is the synthetic horizontal displacement of the midpoint. The results of calculation show that its value decreases from 33.80 to 16.63, reduced by 50.8%. Figure 6 is the steel plate shear section before optimization, and through optimization, the shear quality was obviously improved, which is shown in Figure 7.

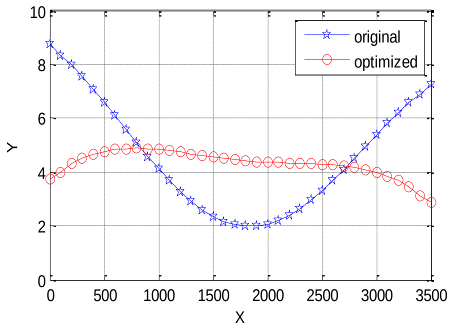

Figure 4. Overlap Amount Curves of Each Testing Point Before and After Optimization

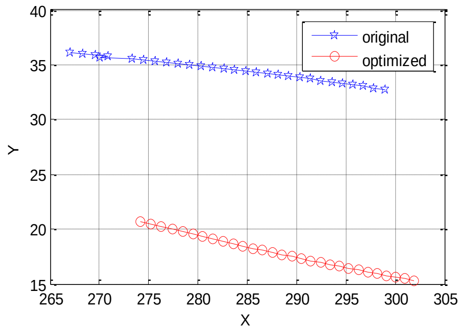

Figure 5. Synthetic Horizontal Displacement of the Midpoints

Figure 6. Steel Plate Shear Section before Optimization

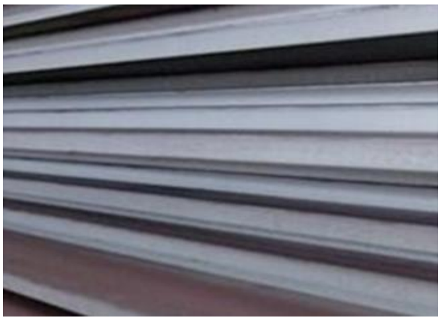

Figure 7. Steel Plate Shear Section after Optimization

6. Conclusions

This article adopts the method of uniform experimental design, fewer samples of space design was used to establish a high fitting precision agent model ,which is based on radial basis function (RBF),through the application of genetic algorithm (GA), The optimal combination of parameters were obtained. The result shows that the uniformity of the overlap has significant improved and the synthetic horizontal displacement is decreased, which is helpful to improve the shear quality of the steel plate and extend the life of the upper blade. The combined use of uniform design and radial basis function can improve test efficiency and reduce test costs. The application has also achieved good results. The method in this paper is general, and can extend to a series of similar analysis.

Acknowledgments

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References

[1] H. C. Zhang and K. Zhang, "State of the art and developing trend for rolling shear of medium plate", Journal of Heavy Machinery, vol. 4, no. 1, **(2013)**, pp. 1-3.
[2] Y. N. Belobrov, Y. G. Bondar' and V. A. Plotnikov, "Reconstruction of the 5000 Plate Mill at Severstal", J. Metallurgist, vol. 47, no. 9, **(2003)**, pp. 364-368.
[3] K. K. Li, "Research on the Design Method of Rolling Shear Mechanism Based on Pure Rolling", D, Dalian University of Technology, **(2009)**.
[4] Y. G. Li, L. F. Ma and Q. X. Huang, "Research on rolling shear with single axle and asymmetric negative offset", Journal of Iron and Steel, vol. 43, no. 2, **(2008)**,pp. 51-55.
[5] L. F. Ma, Q. X. Huang, Y. Li, J. M. Wang and X. G. Wang, "Establishment and application of mathematical model on spatial shear mechanism optimization of new-type steel rolling shear", Journal of Sichuan University(Engineering Science Edition), vol. 40, no. 2, **(2008)**, pp. 170-174.
[6] Z. B. Chu, Q. X. Huang and L. F. Ma, "Experimental study and simulation of kinetics on linkage structure of Rolling-cut bilateral shear", Journal of Sichuan University (Engineering Science Edition), vol. 43, no. 1, **(2011)**, pp. 247-250.
[7] F. S. Sun, H. X. Yang, X. Q. Yan and D. Y. Yang, "Simulation Research of Mechanism Parameter on Cut-to-Length Rolling Shear", Journal of Metallurgical Equipment, vol. 4, no. 8, **(2008)**, pp. 18-21.
[8] X. P. Zhang, G. J. Yang and J. F. Wang, "Analysis of Factors Influence Cutting Quality and Strength parameters of Rolling Cut Shear", Journal of China Mechanical Engineering, vol. 19, no. 7, **(2008)**, pp. 780-784.
[9] W. Chen, Z. F. Qi and Y. D. Zhou, "Constructing uniform designs under mixture discrepancy", Journal of Statistics and Probability Letters, vol. 97, no. 2, **(2015)**, pp. 76-82.
[10] G. Q. Zhang and W. X. Wang, "A citation review on the uniform experimental design", Journal of Applied of Statistics and Management, vol. 32, no. 1, **(2013)**, pp. 89-90.
[11] B. C. Jiang and M. Y. Ai, "Construction of uniform designs without replications", Journal of Complexity, vol. 30, no. 1, **(2014)**, pp. 98-110.
[12] R. L. Hardy, "Multiquadric equations of topography and other irregular surfaces", Journal of Geophysical Research, vol. 76, no. 8, **(2012)**, pp. 1905-1915.
[13] M. F. Hussaina, R. R. Bartonb and S. B. Joshibi, "Metamodeling: radial basis functions versus polynomials", European Journal of Operational Research, vol. 138, no. 1, **(2002)**, pp. 142-154.
[14] D. B. McDonalda, W. J. Granthama, W. L. Taborb and M. J. Murphyc, "Global and Local Optimization Using Radial Basis Function Response Surface Models", Journal of Applied Mathematical Modeling, vol. 31, no. 10, **(2007)**, pp. 2095-2110.
[15] A. Zhiguo, Z. Jie and Z. Jun, "Simulation research for sheet metal forming process based on response surface methodology of radius basis function", Journal of System Simulation, vol. 21, no. 6, **(2009)**, pp. 1557-1561.
[16] Y. Zhang, J. L. Wu, Y. Q. Zhang and L. P. Zhang, "Design Optimization of Centrifugal Pump Using Radial Basis Function Metamodels", Journal of Advances in Mechanical Engineering, vol. 6, no. 12, **(2014)**, pp. 457-542.
[17] P. Zhu, Y. Zhang and G. L. Chen, "Metamodeling development for reliability-based design optimization of automotive body structure", Journal of Computers in Industry, vol. 62, no. 7, **(2011)**, pp. 729-741.

Authors

Yugui Li, born in Shanxi in 1967, is a professor of Taiyuan University of Science and Technology, and gained the doctor's degree at Beijing Institute of Technology in China, Beijing in 2007. His achievements Granted with National 2nd class Progress Awards. He has authored or co-authored more than 20 publications collected by EI or SCI, and holds more 10 Chinese patents. Mr. Li is the executive director and the Deputy Secretary General of Shanxi Mechanical Engineering Society. He is also a leader of Shanxi Province young academic and the leader of Engineering Research Center for Department of Heavy Machinery Education, Taiyuan University of Science and Technology.

Yantao Chu, born in Hebei in 1988, is a Master of Mechanical Engineering in the School of Mechanical Engineering at the Taiyuan University of Science and Technology. His current research interests include Fracture and Damage Mechanics, Computational Mechanics and Mechanical design.