Mechanics & Industry **23**, 24 (2022)
© Z. Rui et al., Published by EDP Sciences 2022
https://doi.org/10.1051/meca/2022014

Mechanics & Industry

Available online at:
www.mechanics-industry.org

Regular Article

Open Access

Application of improved radar chart in the health evaluation model of hydraulic gate

Zhang Rui[1,2], Tian Yahui[1,2], and Li Helin[1,2,*]

[1] School of Mechanical and Power Engineering, Zhengzhou University, Zhengzhou 450001, China
[2] Henan Intelligent Manufacturing Research Institute, Zhengzhou 45001, China

Received: 11 February 2022 / Accepted: 17 May 2022

Abstract. In view of the multi-factor influence of stress, deflection, vibration, corrosion and other factors involved in the state assessment of hydraulic steel gates, established a gate health assessment system including the target layer, criterion layer and indicator layer. A hydraulic health assessment model combining fuzzy analytic hierarchy process and improved radar chart method is proposed. In this method, the fuzzy analytic hierarchy process is used to determine the weight of each index, and then the improved radar chart method is used to evaluate the criterion layer and the target layer respectively, and the gate evaluation level is standardized and drawn into the radar chart. An example of comprehensive evaluation of a radial gate is given, which visually expresses the various factors that affect the gate. While giving the health evaluation result of the gate state, it fully reflects the actual state of all aspects of the gate.

Keywords: Hydraulic gate / health assessment / fuzzy analytic hierarchy process / radar chart / comprehensive evaluation

1 Introduction

As a renewable energy, water conservancy and hydropower is the key development direction for mankind to realize carbon neutralization. Metal equipment in water conservancy and hydropower projects is an important tool for human beings to use water resources, and it is also a key facility to ensure the safe operation of water conservancy projects. At present, a considerable part of the existing hydraulic metal facilities in China have reached the service life, even far beyond the design life. The operation status of these facilities is not clear, and some may have potential safety hazards. The results of accidents in hydraulic metal facilities are usually serious. The health assessment of hydraulic metal structure can effectively prevent accidents and avoid blind investment of funds.

Due to the poor working environment and complex load, long-term service of hydraulic gate is easy to lead to structural damage and failure. Relevant scholars have studied its health assessment methods. Yang Guangming [1] elaborated in detail the detection methods and evaluation methods of various aspects of the gate; Li Jianbin [2] conducted a fuzzy comprehensive evaluation of the gate combined with analytic hierarchy process and mathematical methods; Wei Wenguang [3] introduced entropy weight method and variable weight method to adjust the weight in the comprehensive evaluation. Wang Fei [4] used the game combination algorithm to optimize the gate after determining the subjective and objective weights of the gate. Most methods are aimed at determining the weight of various factors affecting the health status of hydraulic gates.

To solve the problem of how to effectively evaluate and express the state of the gate, the fuzzy analytic hierarchy process and radar chart method are used to evaluate the health status of the gate for the first time. On the basis of determining the health evaluation index system of hydraulic gate, the fuzzy analytic hierarchy process is used to determine the weight of each level and index, and then the dual-level radar chart is used to comprehensively evaluate the criterion level and target level successively. The index factors and evaluation criteria are visualized, which can not only give the evaluation results intuitively by radar graphics, but also give the evaluation value quantitatively by evaluation function, and realize the comprehensive health evaluation of hydraulic gate.

2 Gate health assessment system

The establishment of the index system of hydraulic gates is the basis and key factor for health assessment, and many influencing factors need to be comprehensively considered.

* e-mail: lihelin@gs.zzu.edu.cn

Table 1. Gate evaluation system.

①Target layer	②Criterion layer	③Index layer: x_i
Comprehensive evaluation of gate	Safety	x_1: Primary component $\sigma/[\sigma]$
		x_2: Overload $H_{实}/H_{设}$
		x_3: Ice thickness (cm)
		x_4: Arm stability $\sigma/[\sigma]$
		x_5: Deflection of main beam $l\Delta/l$
	Applicability	x_6: Vibration strength
		x_7: Gas corrosion
		x_8: Quality of parts
		x_9: Sealing performance
	Durability	x_{10}: Operating years
		x_{11}: Rusting condition
		x_{12}: Maintenance

Through the analysis of the accident situation and its causes of hydraulic gates, the main factors affecting the healthy operation of the gates are listed. In the basic project of following the principles of purpose, integrity and operability, the safety evaluation system of hydraulic steel gates is divided into three layers according to the Chinese *Regulations on Safety Appraisal of Sluice*: 1. The target layer. The purpose of evaluation is to comprehensively evaluate hydraulic gates; 2. Criteria layer. It includes three aspects of safety, applicability and durability that affect the operation reliability of hydraulic gates; 3. Indicator layer. The indicator layer contains 12 factors that actually affect the reliable operation of the gate.

3 Pretreatment of indicators

3.1 Standardization of indicators

It can be seen from Table 1 that in the evaluation system of hydraulic gates, there are quantitative indicators and non-quantitative indicators. Quantitative indicators are divided into absolute quantitative indicators and relative quantitative indicators, and the magnitudes of indicators are also different. These indicators need to be standardized before evaluation [5]. Specifically, the values of each index are mapped to the interval (0, 1) through the mapping function. The closer the measured value is to the ideal working condition, the closer it is to 1. On the contrary, the closer it is to the failure state, the closer it is to 0. The non-quantitative indicators are determined by professional operation and maintenance managers.

The quantitative indexes are all smaller and better, so the mapping function can be used by $P\ (x_i)$.

$$P(x_i) = \begin{cases} 1, & x_i \le x_{op} \\ \dfrac{x_i - x_{op}}{x_{\max} - x_{op}}, & x_{op} < x_i < x_{\max} \\ 0, & x_i \ge x_{\max} \end{cases} \tag{1}$$

$P(x_i)$ denotes the value of the original data mapped by the mapping function. x_i, x_{op}, x_{max} represent the input of the original data, the best value and the maximum value of the data, respectively.

3.2 Determine the index weight

As a method of analysis and judgment, Analytic Hierarchy Process (AHP) can effectively combine qualitative and quantitative analysis. It divides a complex problem step by step and form a hierarchical structure, and then determine the relative importance of each factor to a certain index by comparing two factors.Comprehensive human judgment determines the relative importance of the overall sort of factors. However, due to the objective existence of human subjective factors, the constructed judgment matrix is difficult to meet the consistency requirements, so it has certain limitations. As another analysis and judgment method, fuzzy analysis method uses the fuzzy transformation principle and membership principle in mathematics to comprehensively evaluate things [6]. The fuzzy analytic hierarchy process combined with fuzzy method and analytic hierarchy process can give full play to their respective advantages, reduce the influence of human subjective factors, reduce the difference between subjective judgment and objective judgment, and solve the problem of human thinking consistency.

The establishment of fuzzy judgment matrix of gate evaluation index [7] is the first step to determine the weight of gate index by fuzzy analytic hierarchy process. Using the method shown in Table 2, each position value in the matrix is determined. The fuzzy judgment matrix can be expressed as:

$$R = \begin{bmatrix} r_{11} & \dots & r_{1n} \\ \dots & \dots & \dots \\ r_{n1} & \dots & r_{nn} \end{bmatrix}. \tag{2}$$

The consistency process of judgment matrix is:

– The line sum based on the judgment matrix:

$$p_i = \sum_{j=1}^{n} r_{ij} \quad i,j = 1,2,...,n \tag{3}$$

– Establishing the priority relation matrix:

$$P = \begin{bmatrix} p_{11} & \cdots & p_{1n} \\ \cdots & & \cdots \\ p_{n1} & \cdots & p_{nn} \end{bmatrix} \tag{4}$$

where $p_{ij} = (p_i - p_j)/2n + 0.5$ $(i,j = 1,2,...,n)$.
– Determination of relative weight.

The feature vector of fuzzy consistent judgment matrix is calculated. Then using the single layer weight formula, the normalized processing is carried out to obtain the relative weight of each evaluation index factor. The calculation formula is:

$$w_i' = \frac{1}{n} - \frac{1}{2a} + \frac{1}{na}\sum_{j=1}^{n} r_{ij} \quad (i = 1,2,\ldots,n) \tag{5}$$

where w_{i}' is the weight value of the first indicator factor; n is the order of r; $a = (n-1)/2$; r_{ij} is the element value in the judgment matrix, indicating the priority of factor i compared with factor j.

The normalization formula is:

$$w_i = \frac{w_i'}{\sum_{i=1}^{n} w_i'} \tag{6}$$

where W_{i} is the weight of the first indicator factor. According to the above calculation method, the weight of each index of the gate health assessment system is shown in Table 3.

Table 2. Scale judgment criteria and meaning.

Scale	Meaning
0.5	Two factors have the same importance
0.6	One factor is slightly more important than the other
0.7	One factor is more important than the other
0.8	One factor is much more important than the other
0.9	One factor is extremely more important than the other
0.1–0.4	If the comparison between element c_i and element c_j is r_{ij}, then the comparison between element c_j and element c_i is $r_{ji} = 1 - r_{ij}$

4 Construction of gate health assessment model based on improved radar chart

4.1 Radar graphic method

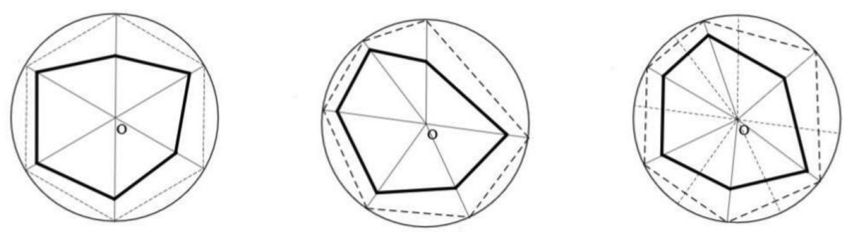
As an intuitive comprehensive evaluation analysis method, radar chart method can scientifically evaluate the research objects with multiple indicators. In the use of radar chart evaluation, not only consider the overall level of the evaluation object, but also consider the relationship between the indicators of the evaluation object, so it is widely used in economic, management, computer, industry, medicine and other fields. The radar chart method is used for comprehensive evaluation [8]. Firstly, the index system of the evaluation object is determined. According to the index system, the corresponding radar chart is drawn, and then the relevant characteristic variables are extracted to give the evaluation results. Overall, the larger the drawing area, the stronger the overall advantage; the smaller the area, the opposite conclusion. When the overall area of the drawn radar graph is constant, the smaller the sum of the peripheral side lengths is, the more balanced the evaluation objects are.

The original radar image is to divide the whole circular area equally according to the total number of indicators, mark the value of each indicator on each indicator axis, and connect each marker point in turn (Fig. 1a). Zheng Huili [9] proposed to calculate the evaluation value of the evaluation object and obtain quantitative comprehensive evaluation results by extracting the area and perimeter of the radar map as the feature vector and using the geometric average of the feature vector as the comprehensive evaluation function. Ding Jiemin [10] proposed a method to determine the sector area according to the arc value corresponding to the index weight size, and draw the radar map clockwise, as shown in Figure 1b. Qiao Pengcheng [11] used the diagonal of the fan-shaped region corresponding to each index as the index axis, and improved the feature vector, so that it not only reflected the independent weight of each index, but also reflected the mutual influence and role of each index, as shown in Figure 1c. At present, many radar graph analysis methods are used to sort different evaluation subjects or different stages of the same subject. The evaluation value changes with the change of the evaluation object index data. Based on the adjustment of radar graphics drawing method, the safety evaluation standard of hydraulic steel gate is introduced to draw radar graphics, which makes the evaluation unified and extends the application scope of the evaluation method. At the same time, when the radar chart is used for comprehensive evaluation, the entropy value of the index is introduced to replace the perimeter to measure the balance of the development of the evaluation object. The greater the difference between the marked data, the smaller the entropy value; on the contrary, the greater the entropy value is. The calculation process of entropy is as follows.

Assuming n objects for a comprehensive evaluation using radar maps, total$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}$

Table 3. Weights of health assessment indicators.

Criterion layer	Criterion layer weight	Index layer	Index weight
Safety	0.5	x_1	0.390
		x_2	0.138
		x_3	0.072
		x_4	0.240
		x_5	0.160
Applicability	0.2	x_6	0.275
		x_7	0.245
		x_8	0.264
		x_9	0.216
Durability	0.3	x_{10}	0.167
		x_{11}	0.567
		x_{12}	0.266



(a) (b) (c)

Fig. 1. Three types of radar charts for comprehensive evaluation of 6 indicators.

the entropy of the jth evaluation object can be expressed as

$$H_j = -\frac{\sum_{i=1}^{m} p_{ij} log_2 p_{ij}}{log_2 m} \tag{8}$$

4.2 Gate health assessment model based on radar chart

4.2.1 Gate evaluation index grade standard and data standardization

At present radar graph method can only sort multiple evaluation objects or sort multiple evaluation states of one evaluation object, cannot complete the evaluation of a single state of a single evaluation object. To solve the above problems, the gate evaluation grade standard is introduced in the health evaluation of the gate. According to *Scrapping Standards of Metal Structures in Water Conservancy and Hydropower Project* (SL226) [12], *Assessment Standards of Equipment Management Levels of Gates and Hoists and Ship Lifts in Water Conservancy and Hydropower Projects* (SL240) [13], and *Manufacturing, Installation and Acceptance Specifications of Steel Gates in Water Conservancy and Hydropower Projects* (GB/T14173) [14], the gate health assessment is divided into four grades A, B, C and D (Tab. 4):

Level A: the gate operates well in general, and all the performances meet the requirements. The main performance is excellent, and there is a safety margin.

Level B: the operation state of the gate is normal, the main performance meets the requirements, and its performance basically meets the requirements;

Level C: the gate can run barely, the main performance indicators basically meet the requirements, but there are security problems;

Level D: The gate cannot operate normally, and the main performance of the index does not meet the requirements.

Before drawing the radar map of the gate, it is necessary to standardize the size of each index of the gate, which can be referred to the levels in Table 4 to correspond to their respective standardized intervals. According to the four levels of A, B, C and D, each interval is divided equally, each interval accounts for 1/4, on this basis to adjust. In determining the indicators x_1, x_2, x_4, x_5, taking into account the current index standard setting interval gradually smaller (followed by 0.8, 0.2, 0.05), and the speed of material performance degradation in the later stage of the gate, in order to better evaluate the condition of the later stage of the gate, the interval is set wide (adjusted from 0.25 to 0.3), and the corresponding interval of the index x_{10} is the same. When setting in the x_3 interval, taking into account the standard A (no ice pressure) is a qualitative

Table 4. Standard table of gate grade.

Gate evaluation grade standard				
x_i: Index	A	B	C	D
x_1: Primary component $\sigma/[\sigma]$	≤0.85	≤1.0	≤1.05	>1.05
x_2: Overload $H_{实}/H_{设}$	≤0.85	≤1.0	≤1.05	>1.05
x_3: Ice thickness(cm)	ice-free	≤10	≤30	>30
x_4: Arm stability$\sigma/[\sigma]$	≤0.85	≤1.0	≤1.05	>1.05
x_5: Deflection of main beam $\Delta l/l$	<0.85/600(750)	<1.0/600(750)	<1.05/600(750)	≥1.05/600(750)
x_6: Vibration strength	No obvious vibration	Local vibration not strong	Global vibration Local intensity	Global strong vibration
$x7$: Gas corrosion	None	slight cavitation	Cavitation damage	Severe cavitation damage
x_8: Quality of parts	Health	Minor damage	severe damage	Loss of parts
x_9: Sealing performance	completely to satisfy the Requirement	basically to satisfy the Requirement	Close to satisfy the requirements	not satisfy the Requirement
x_{10}: Operating years	≤5	≤15	≤30	>30
x_{11}: Rusting condition	No corrosion at all	a small amount of corrosion	More corrosion	Severe corrosion
x_{12}: Maintenance	Periodic	Basic Periodic	Unscheduled	none

state, the reality may only exist two kinds of ice pressure and no ice pressure, so it is set to a single value 1, when there is ice pressure, it decreases linearly according to the thickness of ice pressure. For the qualitative indicators x_6, x_7, x_8, x_9, x_{11}, x_{12}, there is no need to adjust, according to the equal interval processing, the data mapping of each index corresponding interval and mapping function settings are shown in Table 5.

4.2.2 Drawing radar map and comprehensive evaluation

Using Section 3.2 fuzzy analytic hierarchy process to determine the weight of the gate index, the radar charts of A, B, C and D levels based on safety criteria are drawn. The methods are as follows:

- The circle is drawn with O as the center and 1 as the radius.
- The corresponding sector angle is determined according to the weight w_i of each index degree θ_i, according to the order of the index system, the fan area corresponding to each index is divided by virtual lines.Among which, $\theta_i = 2\pi w_i$.
- Draw diagonal lines of each sector area with real lines as indicators x_i, determine the corresponding areas of A, B, C, D levels on the index axis .The dividing point between them, in turn with green, blue, yellow, red real lines the boundary points on each index axis are connected to form polygons. The enclosed area formed between green and blue polygons represents the radar chart shape corresponding to grade A, the enclosed area formed between blue and yellow polygons represents the radar chart shape corresponding to grade B, the enclosed area formed between yellow and red polygons represents the radar chart shape corresponding to grade C, and the enclosed area formed within red polygons represents the radar chart shape corresponding to grade D, as shown in Figure 2a. The radar chart based on applicability criterion and the radar chart based on durability criterion are drawn by the same method. As shown in Figure 2b,c.

Taking the radar map area of the first evaluation object as S_i and entropy value H_j as feature vectors, the comprehensive evaluation result S_I of the object is expressed as

$$S_I = \frac{S_i}{S_{op}} \cdot H_i \tag{9}$$

S_{op} represents the size of an excellent sample of radar graphics in this evaluation. The radar levels of A, B, C and D of the steel gate based on the criterion layer are shown in Table 7.

According to the analysis steps described above, the radar chart based on target layer is drawn according to the comprehensive evaluation results in Table 6, as shown in Figure 3 and calculate the evaluation results, as shown in Table 7.

5 Hydraulic gate example

A reservoir in Henan Province of the Yellow River Basin is a large (I) water conservancy project with flood control, power generation and water supply functions. The dam height is 55 m and the total storage capacity is 1.32 billion m^3. The reservoir was built in December 1959 and completed in August 1965. In February 1970, the irrigation power generation tunnel was added. In 1986, the dam protection and reinforcement project of the reservoir was started. In

Table 5. Standardized mapping table of indicator data.

Type of indicators	Indicator layer	Grade				Mapping function
		A	B	C	D	
Quantitative indicators	x_1, x_2, x_4, x_5	0.8–1.0	0.6–0.8	0.3–0.6	0–0.3	$P(x_i)=\begin{cases}-\dfrac{4}{17}x_i+1, & x_i\le 0.85\\ -\dfrac{4}{3}x_i+\dfrac{29}{15}, & 0.85<x_i\le 1\\ -6x_i+\dfrac{33}{5}, & x_i>1\end{cases}$
	x_3	1.0	0.8–1.0	0.4–0.8	0–0.4	$P(x_i)=-\frac{1}{50}x_i+1, x_i\ge 0$
	x_{10}	0.8–1.0	0.6–0.8	0.3–0.6	0–0.3	$P(x_i)=\begin{cases}-\dfrac{2}{50}x_i+1, x_i\le 5\\ -\dfrac{1}{50}x_i+\dfrac{9}{10}, 5<x_i\end{cases}$
Qualitative indicators	x_6, x_7, x_8, x_9, x_{11}, x_{12}	1.0	0.75	0.5	0.25	$P(x_i)=\begin{cases}1, & \text{when } x_i \text{is Lever} A\\ 0.75, & \text{when} x_i \text{is Lever} B\\ 0.5, & \text{when} x_i \text{is Lever} C\\ 0.25, & \text{when} x_i \text{is Lever} D\end{cases}$

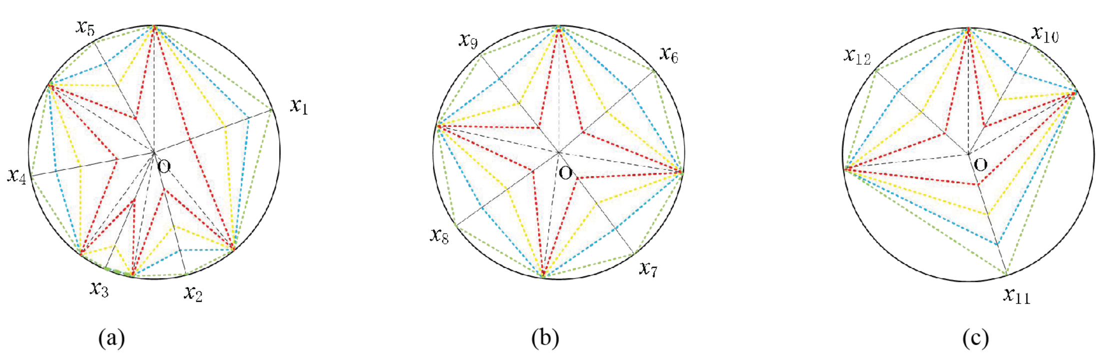


Fig. 2. Radar Chart Based on Criterion Layer. (a) Based on safety criterion; (b) Based on applicability criterion; (c) Based on durability criterion.

2001 and 2003, the government successively invested funds to repair and reinforce the reservoir. The spillway gate of the reservoir is an open-top arc gate, and the main material is Q345B. The vertical height of the gate is 12 m, and the width is 10.5 *m*. The maximum water level is 323 m. The gate number is 3, maximum spillways of 3810 m^3/s, and the total length of the spillway is 435 m. Combined with reservoir operation management.

According to the field inspection, the opening and closing operation of the gate is normal, the appearance of the steel gate is good, and the overall structure has slight deformation. Local position top of the gate.

Water stop with leakage, gate body vibration. The material outside the gate is basically intact, and there is a certain degree of corrosion in general, and some are seriously corroded. The field operation and maintenance

Table 6. Comprehensive evaluation of criterion-level radar chart.

Grade	Radar chart based on safety criterion				Radar chart based on applicability criterion				Radar chart based on durability criterion			
	S_i	H_i	S_{OP}	S_I	S_i	H_i	S_{OP}	S_I	S_i	H_i	S_{OP}	S_I
A	2.20–2.75	0.997, 1		0.798–1	2.12–2.82	1,1		0.752–1	1.69–2.22	0.999, 1		0.761–1
B	1.65–2.20	0.995, 0.997	2.75	0.597–0.798	1.41–2.12	1,1	2.82	0.500–0.752	1.16–1.69	0.996, 0.999	2.22	0.520–0.761
C	0.83–1.65	0.995, 0.995		0.300–0.597	0.71–1.41	1,1		0.252–0.500	0.58–1.16	0.996, 0.996		0.260–0.520
D	0–0.83	0.995		0–0.300	0–0.71	1		0–0.252	0.58	0.996		0–0.260

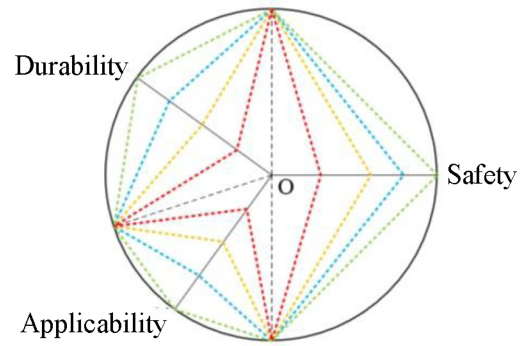


Fig. 3. Radar chart based on the target layer.

Table 7. Comprehensive evaluation of target layer radar map.

Grade	Radar chart based on target layer			
	S_i	H_i	S_{OP}	S_I
A	1.856–2.397	0.9991		0.774, −1
B	1.312–1.856	0.997, 0.999	2.397	0.546–0.774
C	0.658–1.312	0.9970.997		0.274–0.546
D	0–0.658	0.997		0–0.274

Table 8. Index data of the radial gate of the spillway of a reservoir.

Indexes	Original data	Normalized processing
x_1	1.01	0.54
x_2	0.9	0.73
x_3	0	1
x_4	0.93	0.69
x_5	1.04	0.36
x_6	B	0.75
x_7	B	0.75
x_8	B	0.75
x_9	C	0.5
x_{10}	B	0.75
x_{11}	C	0.5
x_{12}	B	0.75

management department can basically patrol and repair according to the requirements.

First of all, through the on-site monitoring of the gate, the analysis of historical documents, numerical calculation, expert scoring based on experience and the internal information of relevant departments, the index data of the gate are shown in Table 8.

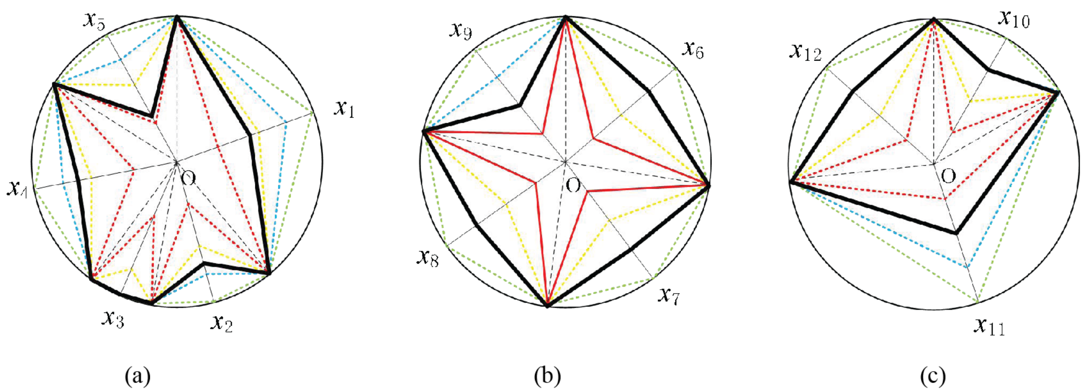


Fig. 4. Example of Radar Chart Based On Criterion Layer a) Based on safety criterion. (b) Based on applicability criterion. (c) Based on durability criterion.

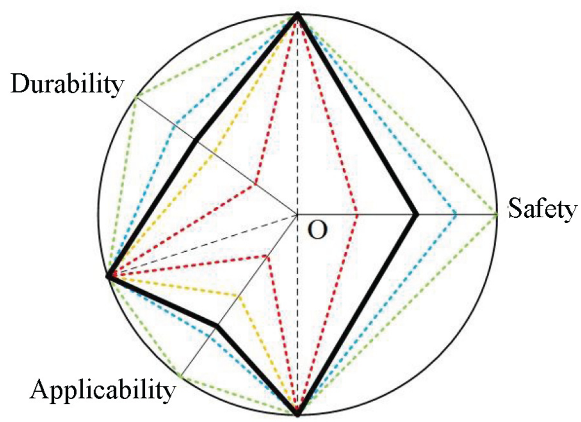


Fig. 5. Example of radar chart based on target layer.

Table 9. Comprehensive evaluation of the criterion-level radar chart of the calculation example.

Radar chart type	The characteristic quantity of radar chart	The charactor values of radar chart
Radar chart based on safety criterion	S_i	1.685
	H_i	0.968
	S_{OP}	2.75
	S_I	0.593
Radar chart based on applicability criterion	S_i	1.959
	H_i	0.990
	S_{OP}	2.82
	S_I	0.688
Radar chart based on durability criterion	S_i	1.421
	H_i	0.985
	S_{OP}	2.22
	S_I	0.630

Table 10. Comprehensive evaluation of the target layer radar map of the calculation example.

Radar chart type	Radar chart based on target layer			
The characteristic quantity of radar chart	S_i	H_i	S_{OP}	S_I
The charactor values of radar chart	1.507	0.998	2.397	0.627

According to the indexes of safety, applicability and durability criteria, the example radar graphics are drawn on the basis of grade standard radar graphics (as shown in Figure 4 black real line), and then the feature vectors are extracted and evaluated (as shown in Tab. 9).

According to the comprehensive evaluation results of the above criteria layer radar map, draw the target layer radar map (as shown in Fig. 5) and calculate the comprehensive evaluation results (as shown in Tab. 10).

In the radar chart based on the safety criterion, the whole figure is near the yellow line, x_2 and x_4 are between the yellow line and the blue line, x_1 and x_5 are between the yellow line and the red line, and x_5 is closer to the red line. From a quantitative point of view, the comprehensive evaluation result of radar chart based on safety criteria $S_I = 0.593$, which is in the range of C level (0.300, 0.597), closer to the critical positions of B and C levels, and is C+ level. From the radar chart based on the applicability criterion, it can be seen that the distribution of each index is relatively uniform, in which $x9$ is slightly worse, and is in the region between the blue line and the yellow line as a whole, $S_I = 0.688$, in the middle of the range of grade B (0.500, 0.752). From the radar chart based on durability criterion, it can be seen that $x10$ and $x12$ are near the blue line and perform well, x_{11} is near the yellow line and perform poorly, $S_I = 0.630$, in the middle of B level (0.520–0.761). The radar chart based on the target layer shows that the applicability and durability of the gate in the example are between blue and yellow, and the safety is near the yellow line. The comprehensive evaluation result is $S_I = 0.627$, which is in the middle position of B grade (0.546,0.774). The main performance of the gate can meet the use requirements. For a single indicator, the gate x_5 indicator, that is, the main beam deflection is too large, and the water sealing performance of x_9 indicator is relatively poor, which should be improved.

6 Summary

In this paper, the radar chart is introduced into the health assessment of hydraulic steel gates, and the gate evaluation system is established by using analytic hierarchy process. According to the gate evaluation grade, two radar charts are drawn based on the criterion layer and the target layer, respectively. The entropy value of radar chart area and index is used for comprehensive evaluation in quantitative analysis and evaluation. Compared with the traditional evaluation method, the established gate condition evaluation model realizes the comprehensive, comprehensive and intuitive expression of gate-related influencing factors, and the evaluation of gate health status can be more refined and reasonable. This method can also be applied to the study of gate health status recession. With the development of intelligent sensing technology and remote operation and maintenance technology, the gate state data can be automatically collected and processed. Combined with radar chart, the analysis and judgment can be carried out. The real-time monitoring of gate state and automatic fault identification can be realized, and the intelligent operation and maintenance can be realized.

References

[1] Y. Guangming, Z. Shengyi, H. Jinyi, C. Dijie, Study on safety inspection and evaluation methods of hydraulic metal structures, Dam Safety **06**, 58–61 (2003)

[2] L. Jianbin, W. Shijing, Y. Zhize, Z. Fan, Safety assessment of hydraulic steel gate based on analytic hierarchy process and fuzzy comprehensive evaluation, Hydropower Energy Sci. **34**, 195–198 (2016)

[3] W. Wenguang, L. Lianghui, H. Wenhao, H. Guoping, P. Jiajun, Fuzzy comprehensive evaluation of hydraulic steel gate safety based on variable weight method, Hydropower **45**, 89–94 (2019)

[4] W. Fei, Z. Shengyi, Z. Xiaojie, Safety and health evaluation of hydraulic steel gate based on game TOPSIS, Hydropower Energy Sci. **39**, 199–202 (2021)

[5] L. Haiying, F. Dong, S. Jian-cheng, Radar chart evaluation model for the status of medium voltage vacuum circuit breakers, Power Syst. Technol. **37**, 2053–2059 (2013)

[6] R. Jiaju, L. Dan, Evaluation of food machinery design scheme based on improved fuzzy analytic hierarchy process, Mach. Des. Manufactur. **03**, 20–22+27 (2017)

[7] C. Meng, A. Shijie, W. Hongwei, Application of improved radar chart method in comprehensive evaluation of ship power system, Equip. Manufactur. Technol. **06**, 166–168 +171 (2018)

[8] Z. Gang, R. Dan, W. Qiang, Z. Xue-hao, Quantitative evaluation of greenness of steel enterprises for manufacturing process, Mach. Des. Manufactur. **S1**, 157–160+164 (2019)

[9] Z. Huili, L. Chen, Z. Danni, Comprehensive evaluation method based on radar chart, J. Nanjing Univ. Posts Telecommun. **02**, 75–79 (2001)

[10] D. Jiemin, L. Weibo, Multi-dimensional data visualization and feature analysis based on radar chart, Mod. Electr. Technol. **33**, 24–26 (2010)

[11] Q. Pengcheng, W. Zhengguo, L. Hui, Comprehensive evaluation method of power quality based on improved radar chart method, Electric Power Autom. Equip. **31**, 88–92 (2011)

[12] SL 226–1998, Metal structure scrap standard for water conservancy and hydropower engineering [S]

[13] SL 240–1999, Water conservancy and hydropower engineering gates and hoists, ship lifts. Equipment management rating standard [S]

[14] GB/T 14173–2008, Specification for manufacture, installation and acceptance of steel gates for water conservancy and hydropower engineering[S]

Cite this article as: Z. Rui, T. Yahui, L. Helin, Application of improved radar chart in the health evaluation model of hydraulic gate, Mechanics & Industry **23**, 24 (2022)