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ASSESSING CROWN-MOUNTED HEAVE COMPENSATOR OF OFFSHORE DRILLING PLATFORM BASED ON THE FUZZY COMPREHENSIVE EVALUATION METHOD

LI Qin， TANG Yujie， HUANG Lingfeng, XU Ziyang

(Key Laboratory of Oil and Gas Equipment (Southwest Petroleum University), Ministry of Education, Chengdu 610500, China)

ABSTRACT

Crown mounted heave compensator(CMC) is the key equipment of offshore drilling platform when operating in deep sea. However, China has not yet mastered the core technology, letting alone mature products. Assessing crown-mounted heave compensator of international manufacturers is the foundation work to achieve its localization, while conventional calculation method is difficult to assess the pros and cons of different designs. Therefore, fuzzy comprehensive evaluation method (FCEM) is used to develop the evaluation index system which includes 3 factors and 11 sub-indices in this paper, and the AHP-Delphi method is used to obtain the weight values of indices. The FCEM is applied to 7 typical crown mounted heave compensators with different principle and design. The results show that ranks for SAHC are all “excellent” but for PHC are all “good”, which indicates that priority should be given to SAHC. In SAHC, the scheme takes one active and two passive cylinders is the best. Vertically arranged cylinders are better than the inclined ones. The study cannot only verify the feasibility of fuzzy comprehensive evaluation method in the evaluation of equipment, but also can provide a scientific basis for China’s self-designed device.

Key Words: drilling platform; crown block; heave compensation; fuzzy comprehensive evaluation; index system

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Introduction

With the development of global oil exploration towards deep sea, the compensation device has become the key equipment which is necessary for offshore drilling platform. Its performance is directly related to the safety and stability of offshore oil and gas development. However, China has not yet mastered its core technology, leaving alone advanced products. All of deep sea drilling equipment are imported from oversea companies, which seriously restricts China's comprehensive development of deep-sea oil and gas resources. Therefore, the evaluation and analysis of the foreign crown mounted heave compensator is the basic work of achieving localization and possessing the independent intellectual property rights of marine equipment, which has important reference value. The overall structure of those company’s crown mounted heave compensators are extremely complex, involving a variety of disciplines, and their layout are designed according to different needs of different marine development environments, which is difficult to use purely mathematical or mechanical calculation for assessing the overall performance of those devices.

During the last decade, equipment evaluation has drawn a lot of attention [1,2]. This method involves the AHP method to establish the evaluation index system, and quantifies the qualitative factors through the fuzzy mathematics theory. It is an effective method for comprehensive evaluation of complex models.

Based on the comparative analysis of the technical conditions of those crown mounted heave compensators, building an evaluation index system including three first-level factors, as well as 11 second-level sub-indices. The AHP-Delphi method is used to obtain the weight values of indices. The FCEM is applied to 7 typical crown mounted heave compensators with different principle and design. The evaluation and analysis results of this paper not only provide a scientific reference for the independent design of China's own crown mounted heave compensator(CMC), but also has great significance for achieving its localization.

1 Comparative Analysis on Technical Parameters of Crane Compensation Device

1.1 Passive Heave Compensator

Passive heave compensator(PHC) is illustrated as Fig.1, which consists of floating crown block, rocker arm, supporting structure, compensator cylinder, accumulator and high pressure vessels. The supporting structure is composed of crown block frame——where floating crown block is installed——crown block track and top frame.

The compensator cylinder plunger is articulated on the main body of the floating crown block to support it, with the crown block as the center symmetrical distribution. The compensation cylinder is connected to the accumulator and the pressure in the accumulator can be adjusted. The rocker arm is an auxiliary pulley with connecting rod mounted around the crown block, which acts to keep the length of the wire rope between the winch and the dead point, thereby reducing the number of turns of the wire rope on the winch to increase its life.

Passive heave compensator is equivalent to a liquid gas spring. When the platform (ship) rises, the crown block moves downward relative to the track, as the piston of compensator cylinder retracts and compress the gas of the main accumulator, compensating for the displacement of the platform (ship) and storing energy. When the platform (ship) sank, it moves in the opposite state. Passive heave compensator does not require additional power supply, but the compensation effect is not that good and its response is lagging and unstable.

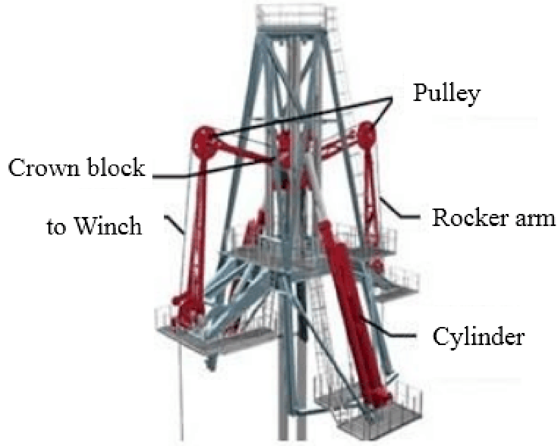

Fig.1 Passive Heave Compensator

1.2 Semi-Active Heave Compensator

In order to overcome the shortcomings of the passive heave compensator and improve the compensation accuracy, the active heave compensator was invented (AHC). Installed with motion reference unit, sensor, hydraulic system and electronic control system, AHC can achieve the precise compensation of the heave movement through control the pressure of compensation cylinder. However, due to its high energy consumption, AHC is used with PHC in most cases, which is called the Semi-Active Heave Compensator(SAHC), as illustrated in Fig.2.

Fig.2 Semi-Active Heave Compensator

1.3 Scheme Comparison Analysis

With the depth of deep-sea oil and gas exploration continues to refresh the record, floating platform requires more on the carrying capacity and compensation stroke of heave compensators. In order to meet the different requirements of sea conditions and working conditions for deep sea operations in different places, international manufacturers have provided standardized and serialized crown mounted heave compensators [3-7]. Results of contrast analysis of schemes of those products can been see through Table 1.

Tab.1 Crown mounted heave compensators of International manufacturers

Manufacturer	Form	Cylinder Number	Characteristics
National Oilwell Varco	PHC	2	Under crown block vertical symmetry.
	SAHC	3	Under crown block vertical symmetry (Passive Cylinder) ; Above crown block vertical (Active Cylinder)
Caster Drilling Solution	PHC	2	Above crown block Vertical symmetry.
AKER	PHC	2	Under crown block Tilt symmetry.
	SAHC	3	Parallel arrangement under crown block vertical distribution PHC is in the middle
Cameron	SAHC	3	Parallel arrangement under crown block vertical distribution AHC is in the middle
Control Flow	SAHC	2	Composite cylinder under crown block vertical symmertry

(1) As for the compensation form, most products are semi-active compensators, accounting for 57%。

(2) As for the numbers of cylinder, all PHC products use two cylinders ; In SAHC, 50 percent of products use two passive cylinders plus one active cylinder, while other products which use two composite cylinders or one passive cylinder plus two active cylinders, accounting for 25 percent respectively.

(3) As for the angles of cylinder, all products use vertically arranged cylinders except AKER's PHC product which used tilted arrangement.

(4) As for the installation location of cylinder, all cylinders of PHC products are under the crown block; In SAHC, all products arrange PHC cylinders under the crown block and the AHC cylinders above it. While Cameron’s SAHC put all cylinders upside down.

1.4 Comparison of technical parameters

Table 2 shows the specific technical parameters for each manufacturer's product:

(1) As for the carrying capability, the static load of SAHC up to 11350 kilonewton, which is 1.25 times of the PHC's; the compensate load of SAHC up to 6800 kilonewton, which is 1.5 times of the PHC's.

(2) As for the stroke, all products can reach 25 foot, which is depended on the local exploration environment.

(3) As for the speed, the maximum compensation speed does not exceed 1.31m/s due to the manufacturing process.

Tab.2 Technical parameters of International manufacturer's products

Manufacturer	Form	parameters			
		Static Load /kN	Comp. Load /kN	Stroke /m	Comp. Speed /m/s
National Oilwell Varco	PHC	9075	4537	7.62	1.22
	SAHC	11350	6800	7.62	1.31
Caster Drilling Solution	PHC	9065	4214	7.62	1.31
AKER	PHC	8898	4449	7.62	1.31
	SAHC	11350	6800	7.62	1.22
Cameron	SAHC	8898	4449	7.62	1.25
Control Flow	SAHC	8898	4449	7.62	1.31

2 Fuzzy Comprehensive Evaluation

2.1 Establishment of Evaluation Index System

The primary task of fuzzy comprehensive evaluation is to establish the evaluation index system. The construction of the evaluation index system should follow the following three principles:

(a) comprehensive and representative - the indices can reflect the main situation of the compensation device and do not overlap with each other. (b) scientific – index can objectively explain the characteristics of compensation devices. (c) operability—data through observation or measurement easy to obtain, reliable and comparable data sources.

According to the above principles, the use of analytic hierarchy process to select a typical or easily obtained indicators to avoid the complexity of the model.

Crown mounted heave compensator is used on floating drilling vessels, which is usually operated offshore. The first step is to examine whether its structural characteristics meet operation requirements and specifications. As the CMC is installed in the top of the drill rig which up to tens of meters, so it has a high position and large load, hence its safety and stability is very important. And once the components of the CMC are damaged and are not repaired in time, the whole rig system may be rendered ineffective, so its maintainability is also an aspect to be considered. Besides, the applicability of the derrick reflects the degree of compatibility between the compensator and the derrick.

In addition, the technical parameters of the CMC reflect the ability to compensate in harsh sea conditions and operating conditions. The maximum static load and compensated load of the compensator determine the operation depth tor of the floating drilling device. And the greater the compensation stroke of the device, the greater the ability to adapt to the harsh sea conditions, the greater the compensation speed, the faster the platform's response to the heave movement. At last, offshore oil and gas exploration and development operations need to be cost controlled, compensator selection of floating drilling equipment should also consider the price and use-costs. However, more other data quality elements are not selected since the lack of judgment criteria and techniques in China.

2.2 Determining the weight values of indices

The selected evaluation index system for CMC includes 3 layers ($B = \{B_1,B_2,B_3\}$) and 11 sub-indices ($C= \{C_1,C_2,C_3\ldots,C_m\}$) .

Through the 1-9 scale method [8], compare three layer factors in accordance with the importance, which formed judgment matrix A. The weight values of three layer factors are shown in Figure 3.

Tab.3 Judgment Matrix and Weight Values

of Three Factors

A	B_1	B_2	B_3	WV
B_1	1	1/2	3	0.310
B_2	2	1	2	0.517
B_3	1/3	1/2	1	0.173

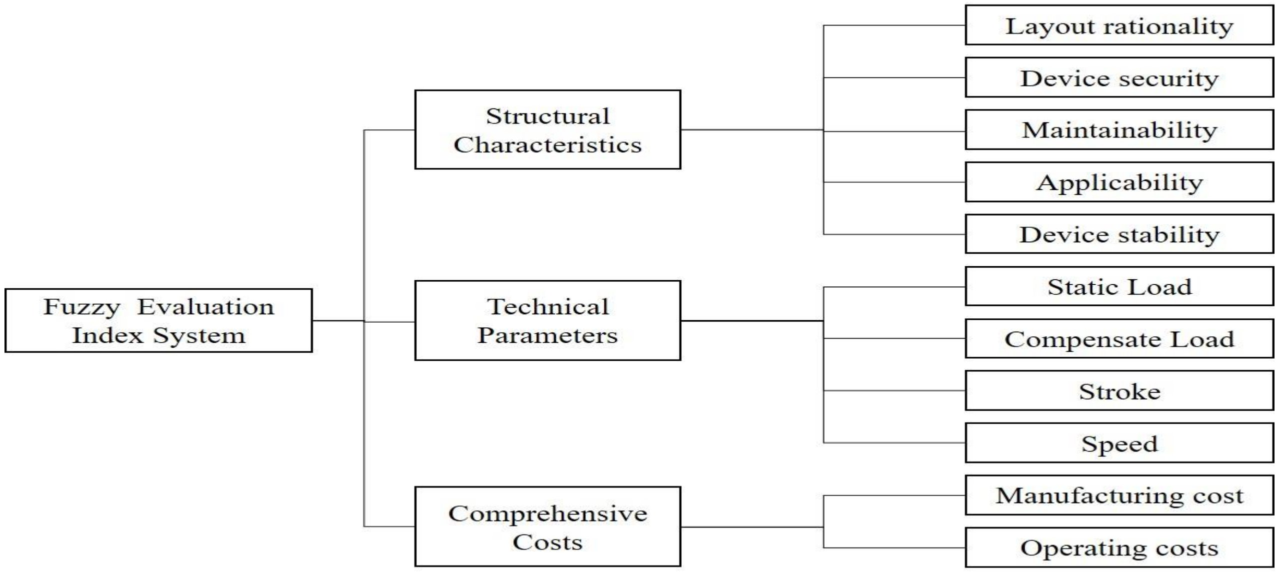

Fig.3 Fuzzy Evaluation Index System for CMC

The consistency ration (CR) is used to determine the consistency of judgmental matrix and the CR should less than 0.1 for the consistency of matrix. The CR can be calculated through the consistency index (CI) dividing by random index (RI) [9]。 The CR of judgment matrix is 0.0224<0.1, indicating that CR fulfils requirements.

The judgement matrixes and weight values of 11 sub-indices are calculated through the 1-9 scale method (shown in Tab.4~Tab.9).

Tab.4 Judgment Matrix and Weight Values

of Structural Characteristics（CR<0.1）

B_1	C_1	C_2	C_3	C_4	C_5	WV
C_1	1	1/3	1	5	1/2	0.147
C_2	3	1	3	4	1/3	0.216
C_3	1	1/3	1	5	1/4	0.115
C_4	1/5	1/4	1/5	1	1/6	0.051
C_5	2	3	4	6	1	0.471

Tab.5 Judgment Matrix and Weight Values

of Technical Parameters（CR<0.1）

B_2	C_6	C_7	C_8	C_9	WV
C_6	1	2	3	5	0.496
C_7	1/2	1	1	2	0.224
C_8	1/3	1	1	1	0.168
C_9	1/5	1/2	1	1	0.112

Tab.6 Judgment Matrix and Weight Values

of Comprehensive Costs（CR<0.1）

B_3	C_{10}	C_{11}	WV
C_{10}	1	1/3	0.25
C_{11}	3	1	0.75

2.3 Determining the evaluation criteria and ranks

The Fuzzy Comprehensive Evaluation includes three ranks of “excellent’’, “good”,” ordinary”, allocating the corresponding scores of 90, 80, and 70, respectively (shown in Table 7). In this study, the evaluation criteria are determined on the basis of GB/T 23511-2009, DNV-OSS-101, DNV-RP-H103, ABS and IMO rules, as well as some suggestions from experts and manufacturers [13-17].

2.4 Determining the fuzzy relationship matrix

Based on the evaluation index system and assessing rules, the fuzzy relationship matrix is ascertained as:

$$F = \left(f_{ij}\right)_{m\times r} = \begin{pmatrix} f_{11} & \cdots & f_{1r} \\ \cdots & \ddots & \cdots \\ f_{m1} & \cdots & f_{mr} \end{pmatrix} \qquad (1)$$

where, f_{ij} represents the fuzzy membership of the ith index belonging to the jth rank.

Based on the established evaluation index system, the factors that affect the comprehensive evaluation of CMC include qualitative and quantitative indicators. For qualitative factors, The AHP-Delphi method is used to obtain the weight values of indices and the scores are graded according to Table 8. Then the ranking of each factor is normalized according to the number of experts, result of which is the membership of the different criteria corresponding to the sub-indices. For the quantitative factors, because of its physical significance, the original data need to be normalized, and then according to the following formula to calculate the index membership.

Tab.7 Rules for assessing the performance of CMC.

index	rank（scores）		
	excellent（90）	good（80）	ordinary（70）
Layout rationality	Very reasonable	Generally reasonable	Reluctantly reasonable
Device security	Very safe	Generally safe	Meet the requirements
Maintainability	Easy to maintain	Reluctantly maintained	Inconvenient to maintain
Applicability	Fully applicable	Basic applicable	Applicable after modification
Device stability	Fully meet the specification requirements	Close to regulatory requirements	Reluctantly meet the specification requirements
Static Load（kN）	≥11350	≥9080	≥5900
Compensate Load（kN）	≥6800	≥4540	≥2700
Stroke（m）	≥7.62	≥6.096	≥5.4864
Speed（m/s）	≥1.31	≥1.22	≥0.85
Manufacturing cost	Low cost	The cost is higher	expensive
Operating costs	No energy consumption, low maintenance costs	Low energy consumption and low maintenance costs	High energy consumption, high maintenance costs

$$f_{ik}(x)=\begin{cases}1 & x\geq v_{ik}\\ \dfrac{x-v_{i(k+1)}}{v_{ik}-v_{i(k+1)}} & v_{i(k+1)}\leq x\leq v_{ik} \quad k=1\\ 0 & x\leq v_{i(k+1)}\end{cases} \tag{2}$$

$$f_{ik}(x)=\begin{cases}0 & x\geq v_{i(k-1)}\\ \dfrac{v_{i(k-1)}-x}{v_{i(k-1)}-v_{ik}} & v_{ik}\leq x\leq v_{i(k-1)} \quad k=2\\ \dfrac{x-v_{i(k+1)}}{v_{ik}-v_{i(k+1)}} & v_{i(k+1)}\leq x\leq v_{ik}\end{cases} \tag{3}$$

$$f_{ik}(x)=\begin{cases}1 & x\leq v_{ik}\\ \dfrac{v_{i(k-1)}-x}{v_{i(k-1)}-v_{ik}} & v_{ik}\leq x\leq v_{i(k-1)} \quad k=3\\ 0 & v_{i(k-1)}\leq x\end{cases} \tag{4}$$

where, x is the select value of the ith index; v_{ik} is the kth rank threshold of the ith index; and f_{ik} is the fuzzy membership of the ith index belonging to the kth rank.

Tab.8 Ranking Score for Qualitative factors

Rank	Percentage interval	median
Excellent	100~90	95
Good	90~80	85
Ordianary	80~70	75

2.5 Calculating comprehensive evaluation grade

As shown in Eq.(5), fuzzy membership of comprehensive evaluation classes can be calculated by multiplying weight vector and fuzzy relationship matrix.

$$E = W \otimes F = \begin{pmatrix} w_1 & w_2 & \cdots & w_m \end{pmatrix} \begin{pmatrix} f_{11} & \cdots & f_{1r} \\ \cdots & \ddots & \cdots \\ f_{m1} & \cdots & f_{mr} \end{pmatrix} \tag{5}$$
$$= \begin{pmatrix} E_1 & E_2 & \cdots & E_r \end{pmatrix}$$

where, w_m is the weight of the mth index for assessing CMC and m=11; E_r is the fuzzy membership of CMC belonging to the rth rank and r=3.

Fuzzy comprehensive evaluation rank is determined by the maximum membership degree, in order to distinguish between the advantages and disadvantages of the same membership in the product, the evaluation vector can be multiplied by the median of the three ranks in Table 3.

$$Z = E \otimes B = \begin{pmatrix} E_1 & E_2 & \cdots & E_r \end{pmatrix} \begin{pmatrix} B_1 & B_2 & \cdots & B_r \end{pmatrix} \quad (6)$$

Where, B is the median and r is the rank.

The CMC is “ordinary” when $70 < Z \leq 8$; is “good” when $80 < Z \leq 90$; and is “excellent” when $90 < Z$. The assessing results have been validated by the data provided by suppliers and users.

3 Assessment results and analysis

3.1 Comprehensive assessment results

A comprehensive assessment of 7 different compensation principle and design scheme of the crown mounted heave compensator of international manufactures is shown in Table 1. According to the above formula, the assessment results of each product can be acknowledged. As shown in Table 9, the score distribution is shown in Figure 4.

Tab.9 Fuzzy comprehensive evaluation results

manufacturers	Compensation forms	Composite scores
National Oilwell Varco	PHC	88.71
	SAHC	95.41
Caster Drilling Solution	PHC	86.18
AKER	PHC	84.18
	SAHC	93.21
Cameron	SAHC	92.35
Control Flow	SAHC	91.07

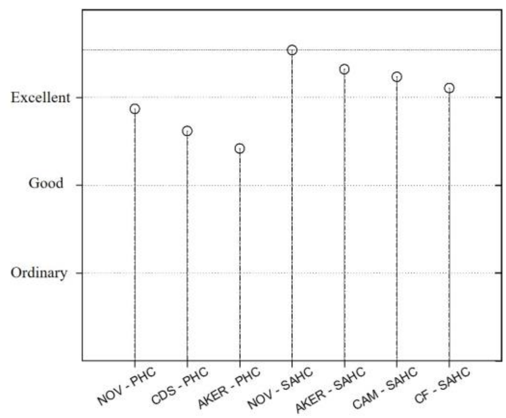

Fig.4 Fuzzy comprehensive evaluation map of crown mounted heave compensator

3.2 Result analysis

According to the product evaluation results, we can get : ①All SAHC products are excellent, with an average score of 93.01 points, in which the design scheme with two passive cylinder plus 1 active cylinders of NOV company product gets highest score of 95.41; ②All PHC products are good, with an average score of 86.36 points, in which the hydraulic cylinder using the vertical arrangement of the NOV company's products gets the highest score of 88.71; ③The Control Flow product with the compound hydraulic cylinder gets lowest score in the semi active heave compensator, and the lowest score of the AKER product is obtained by using the hydraulic cylinder in PHC products.

The above results show that the semi active heave compensator with one active cylinder and two passive cylinders is the preferred option for deep-sea operation, and the layout angle of hydraulic cylinder shall be in vertical arrangement.

4 Conclusions

(1) The study establishes a fuzzy comprehensive evaluation model (FCEM), including 3 factors and 11 sub-indices, based on fuzzy set and the AHP method for assessing Crown Mounted Compensator (CMC) of international manufactures.

(2) The FCEM is applied to 7 typical crown mounted heave compensators with different principle and design. Results show that all SAHC products are "excellent" and all PHC products are "good", indicating that Semi-Active Heave Compensator is the best choice in offshore operation.

(3) In SAHC, products using two active cylinders plus one passive cylinder is the best scheme, and the arrangement of the hydraulic cylinders takes precedence over the vertical arrangement. The study cannot only verify the feasibility of fuzzy comprehensive evaluation method in the evaluation of equipment, but also can provide a scientific basis for China's self-designed device.

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