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Research on Reliability Verification of Old Gas Regulator

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Abstract

In order to solve the problems of low operation reliability and high safety risk of old gas regulators,7471 in-service old gas regulators in Suining Branch of Sichuan Chuangang Gas Co., Ltd.were taken as the research object, and 287 were stratified sampled according to working years, using areas, pressure regulating ranges and brands. The reliability verification experiments of rubber diaphragms and springs were carried out.According to the national standard, the gas resistance, tensile properties, compression permanent deformation and spring accuracy grade (GB27790-2020) and test of rubber diaphragm were completed. The results showed that the gas resistance of 27,28 and 29 groups of diaphragms was the best (the mass / volume change rate was close to 0, and the coefficient of variation was less than 0.5). The qualified rate of grade II accuracy of 41 spring samples was only 19.5 %, and the unqualified was mainly due to the verticality exceeding the limit (maximum 12.2 mm). The tensile strength of RTZ-43 / 80 N membrane is 10.47 MPa, and the compression permanent deformation rate is less than 5 %. The research provides data support for the replacement cycle formulation and brand selection of old regulator components.

Keywords

Old Gas Regulator; Rubber Diaphragm; Spring; Reliability Verification; Gas Resistance.

1. Introduction

The gas pressure regulator is the core pressure stabilizing device of the transmission and distribution system, which directly determines the pressure stability and gas safety of the user end. If the diaphragm of the regulator is aged and the spring fails, it is easy to cause pressure fluctuation, incomplete combustion and even explosion accidents. Sichuan Chuangang Gas Suining Branch currently has 7471 old voltage regulators, of which 38 % have not replaced core components for more than 14 years, with outstanding potential safety risks.

Scholars at home and abroad have carried out relevant research on the reliability of the voltage regulator : Yao Ting[1]optimized the structural parameters of the voltage regulator through SolidWorks modeling to improve the voltage regulation accuracy ; based on the Weibull model, Yan Rongsong[2]etal.found that the reliability of the pre-meter regulator after 16 years of operation was reduced to less than 0.5; houetal.[3]used MATLAB / Simulink simulation to propose a diaphragm performance optimization scheme ; peietal.[4]analyzed the influence of spring effect on the accuracy of voltage stabilization. However, the existing research mostly focuses on new equipment or a single component, and there are few system verifications for the core components of multi-brand and long-service old regulators.

Through multi-dimensional experiments, this study quantifies the performance degradation law of diaphragms and springs of different brands and years of regulators, provides a theoretical basis for equipment maintenance and replacement, and is of great significance for ensuring the safe operation of gas systems.

2. Experimental Scheme

2.1. Sample Sampling Design

In order to ensure the representativeness of the samples, 287 voltage regulators are selected by the ' four-dimensional stratified sampling method ', covering the key difference dimensions of the equipment : the working years cover three intervals of 14-17 years (107 sets), 17-20 years (88 sets) and more than 20 years (92 sets), focusing on the equipment with over-design life (10 years). The use area includes three types of areas : urban area (95 units, stable pipe network pressure), township (102 units, large fluctuation of gas load) and mountainous area (90 units, complex temperature and humidity environment), and the influence of environment on the performance of components is analyzed. In the range of pressure regulation, 152 sets of equipment operating across pressure levels (inlet pressure 0.02-0.4 MPa, outlet pressure 1-5 kPa) are preferentially selected, and 135 sets of equipment with conventional pressure levels (inlet pressure 0.1-0.2 MPa, outlet pressure 2-3 kPa) are selected to compare the degradation differences of components under different loads. The brand covers six mainstream brands : Chongqing Jichuan, Chongqing Shancheng, Chuantian, Jensen, Fisher Jiuan, and Chengdu Huatai.Each brand selects 45 to 50 devices to avoid the impact of brand bias on the experimental results.

After dismantling the 287 regulators, 29 groups of rubber diaphragms (each group contains 3 parallel samples) and 41 spring samples were obtained. The thickness of the rubber diaphragm is between 0.68-2.8mm, the diameter of the spring section is 1.42-3.02mm, and the middle diameter is 9.46-37.14mm.All of them are taken from the core functional area of the regulator (the diaphragm is the pressure sensing area, and the spring is the voltage regulation area).

2.2. Experimental Standards and Equipment

The experiment strictly follows the national standards and ensures the authority and comparability of the data. The core test items and the equipment used are as follows :

The gas resistance test of rubber diaphragm was carried out according to GB / T 1690-2010 ' Liquid resistance test method of vulcanized rubber or thermoplastic rubber '.Analytical pure n-pentane (C5 + hydrocarbon component in simulated gas) was used as soaking medium and soaked at 23 ± 2 °C for 72 h. The mass of the sample before and after soaking was measured by METTLER TOLEDO precision analytical balance (precision 0.1 mg), and the volume change was measured by drainage method.

According to GB528-2009 ' Determination of tensile stress and strain properties of vulcanized rubber or thermoplastic rubber ', the tensile strength (TS) and elongation at break (Eb) were measured by SHT4600 electronic universal material testing machine (loading speed 500mm / min).

Compression permanent deformation test of rubber diaphragmAccording to GB / T 7759.1-2015 " Determination of compression permanent deformation of vulcanized rubber or thermoplastic rubber, " the B-type cylindrical sample (diameter 13.0 ± 0.5mm, height 6.3 ± 0.3mm) was used to compress the sample by 25 % at 23 ± 2 °C for 72 h, and the height change was measured by a vernier caliper (accuracy 0.02mm) after 30 min recovery.

The spring accuracy grade and stiffness test refer to GB27790-2020 ' Town Gas Regulator ' and GB / T1239.2-2009 ' Technical Conditions for Cold-rolled Cylindrical Spiral Springs-Part 2 : Compression Springs '. The cross-section diameter, middle diameter and free height of the spring are measured by a vernier caliper, and the verticality is measured by a wide seat angle ruler with a stopper ruler (accuracy 0.01 mm). The spring stiffness coefficient ($K = \Delta F / \Delta$) was calculated by using an electronic universal material testing machine (compression speed of 20mm / min) and taking the total deformation of 30 % to 70 %.

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Auxiliary equipment includes HONGJIAN constant humidity incubator (temperature control ± 2 °C, humidity control 50 ± 10 % RH), type 2 rubber cutter (according to GB / T 528 - 2009 Appendix A requirements) and so on.

2.3. Experimental Process

The experiment was carried out in three stages:

2.3.1. Sample Pretreatment

All samples were adjusted for 3h in the environment (23 ± 2 °C, 50 ± 10 % RH) specified in GB / T 2941-2006 ' General Procedures for Preparation and Adjustment of Rubber Physical Test Methods '.After the appearance inspection without cracks, bubbles and other defects, the initial size and quality were recorded.

2.3.2. Core Test

In the gas resistance test of rubber diaphragm, the mass and volume measurements were completed within 5 minutes after soaking for 72 hours, and then the samples were placed in a ventilated environment for drying for 24 hours, and retested again ; the tensile and spring stiffness tests of the diaphragm were repeated three times, and the average value was taken to reduce the random error. In the spring accuracy test, the verticality needs to measure 4 points on both ends, and the maximum value is taken as the final result.

2.3.3. Data Processing

According to the national standard formula to calculate the performance indicators, such as mass change rate Δm = (mass after soaking-mass before soaking) / mass before soaking × 100 %, compression permanent deformation rate C = (initial height-height after recovery) / (initial height-limiter height) × 100 %, analyze the performance differences of different samples.

3. Experimental Results and Analysis

3.1. Analysis of Gas Resistance of Rubber Diaphragm

The gas resistance of rubber diaphragm directly reflects its long-term stability in gas environment. The experimental results show that the performance of diaphragms with different brands and service years is significantly different:

3.1.1. High-quality Performance Group

Leshan Chuantian membrane manufactured in 2019 and Hebei Ruixing membrane manufactured in 2018 performed best. After soaking for 72 h, the mass change rate was between-0.006 % and 0.002 %, and the volume change rate was between-0.674 % and 0.335 %. After drying for 24 h, the mass change rate decreased to − 0.034 % ~ − 0.028 %, the volume change rate decreased to − 0.911 % ~ − 0.601 %, and the coefficient of variation of the performance of different samples in the same group was less than 0.5, indicating that this kind of membrane had good compatibility with gas components, no obvious swelling[5]or component loss, and strong long-term service stability.

3.1.2. Medium Performance Group

RTZ-31 series diaphragms manufactured by Chengdu Huatai from 2012 to 2013, after soaking for 72 h, the mass change rate is − 0.015 % ~ − 0.010 %, the volume change rate is − 0.516 % ~ − 0.388 %, and the performance recovery rate after drying is over 85 %, which can meet the daily operation requirements, but the performance changes need to be monitored regularly.

3.1.3. Deterioration Performance Group

The performance of the diaphragms manufactured by Jensen in 2007 and Wantong in 2007 was significantly degraded. After 72 hours of immersion, the mass change rate was − 0.140 % ~ −

0.059 %, and the volume change rate of some diaphragms was 1.400 %. After drying for 24 h, the mass change rate was still less than-0.098 %, which could not be restored to the initial state. It was speculated that the plasticizer in the diaphragm was precipitated[6]and the rubber molecular chain was broken due to long-term service. Priority should be given to replacement to avoid safety risks.

Table 1. Experimental data sorting results

Group number	Averag e mass change rate of foam in 72h	Average volume change rate of bubble 72h	The average value of mass change rate in 24 hours	The average value of volume change rate in 24 h was put in.	The standard deviation of 72h mass change rate	The standard deviation of bubble 72h volume change rate	Standard deviation of 24 h mass change rate	Standard deviation of volume change rate in 24 hours	The coefficient of variation of 72h mass change rate	The coefficient of variation of 72h volume change rate of bubble	The coefficient of variation of 24 h mass change rate	24 h volume change rate coefficient of variation
1	0.024	-0.852	0.009	-0.892	0.001	2.801	0.001	0.351	0.054	3.287	0.088	0.393
2	0.015	-0.437	-0.022	-0.922	0.009	0.254	0.009	0.130	0.596	0.582	0.403	0.141
3	0.025	-0.773	0.001	-1.056	0.002	0.166	0.002	0.195	0.064	0.215	2.617	0.185
4	0.020	-0.249	0.003	-0.733	0.002	0.301	0.007	0.110	0.106	1.211	1.958	0.151
5	0.019	-0.457	-0.003	-1.209	0.002	0.244	0.003	0.138	0.082	0.534	0.828	0.114
6	0.016	-0.850	-0.003	-0.975	0.007	0.373	0.002	0.569	0.416	0.439	0.612	0.583
7	0.018	-0.197	-0.006	-0.856	0.002	0.230	0.004	0.335	0.129	1.168	0.702	0.391
8	-0.015	-0.320	-0.067	-1.215	0.004	0.331	0.004	0.258	0.277	1.036	0.062	0.213
9	-0.024	0.305	-0.066	-1.279	0.006	0.821	0.003	0.611	0.235	2.695	0.046	0.477
10	-0.059	1.400	-0.098	-1.217	0.020	1.233	0.008	0.475	0.346	0.881	0.081	0.390
11	-0.093	0.904	-0.146	-0.679	0.005	0.774	0.005	0.501	0.051	0.856	0.034	0.737
12	-0.140	-0.897	-0.160	-1.405	0.006	0.735	0.008	1.026	0.045	0.819	0.051	0.730
13	0.012	-0.516	-0.028	-0.775	0.005	0.333	0.006	0.405	0.402	0.646	0.227	0.523
14	0.015	-0.768	-0.024	-0.907	0.006	0.235	0.006	0.391	0.413	0.306	0.272	0.431
15	0.022	-0.490	-0.010	-0.893	0.003	0.600	0.002	0.231	0.141	1.225	0.221	0.258
16	0.024	0.219	-0.003	-0.881	0.005	0.563	0.004	0.457	0.216	2.567	1.424	0.519
17	-0.040	-0.388	-0.079	-0.921	0.009	0.196	0.026	0.152	0.225	0.506	0.331	0.165
18	-0.032	1.893	-0.076	-1.007	0.005	1.256	0.007	0.457	0.153	0.664	0.093	0.454
19	0.003	0.439	-0.037	-0.568	0.002	0.336	0.006	0.637	0.514	0.765	0.155	1.121
20	-0.016	-0.291	-0.049	-0.416	0.005	0.732	0.007	0.581	0.313	2.513	0.134	1.399
21	0.004	0.097	-0.042	-0.799	0.005	0.620	0.004	0.433	1.166	6.379	0.107	0.542
22	-0.021	-0.739	-0.060	-0.910	0.034	0.200	0.033	0.180	1.620	0.270	0.552	0.198
23	-0.020	-0.596	-0.052	-0.933	0.009	0.370	0.009	0.372	0.437	0.621	0.165	0.399
24	-0.026	-0.580	-0.066	-0.925	0.013	0.246	0.014	0.223	0.502	0.423	0.220	0.241
25	-0.034	-0.530	-0.069	-0.566	0.020	0.271	0.014	0.367	0.587	0.511	0.207	0.648
26	-0.029	-0.533	-0.068	-0.916	0.011	0.284	0.010	0.143	0.373	0.534	0.149	0.156
27	-0.006	-0.674	-0.034	-0.911	0.004	0.240	0.018	0.305	0.634	0.356	0.540	0.335
28	-0.005	-0.318	-0.028	-0.601	0.002	0.163	0.006	0.252	0.526	0.512	0.227	0.419
29	0.002	0.335	-0.034	-1.184	0.012	1.568	0.014	0.349	5.507	4.679	0.404	0.295

3.2. Spring Accuracy Level and Stiffness Analysis

As the key component of voltage regulator[7], the accuracy and stiffness of spring directly affect the accuracy of voltage regulation. The experimental results are as follows :

3.2.1. The Low Qualified Rate of the Accuracy Grade

Table 2. Descriptive statistical analysis results

Number	Measuring projects	Mean value mm	Standard deviation mm	Minimum, mm	Maximum mm
1	Section diameter (d)	2.42	0.72	1.42	3.02
2	Measuring inner diameter(D1)	25.66	11.47	8.12	34.62
3	Measuring outer diameter(D2)	30.35	12.51	11.31	40.32
4	Mean diameter of coil(D)	27.77	12.04	9.46	37.14
5	Unsupported height(H0)	77.77	34.65	24.96	100.42
6	Verticality	2.84	2.61	0.1	3.8

Only 8 of the 41 spring samples meet the accuracy requirements of grade II (verticality ≤ min { 1mm, spring diameter / 20 }), and the qualified rate is only 19.5 % ; the unqualified samples were all due to the verticality overrun, and the maximum verticality reached 12.2 mm (Kehuatong factory regulator supporting spring in 2005), far exceeding the standard limit ;

3.2.2. The Correlation between Size and Performance

The qualified rate of small-sized springs with a medium diameter of about 9.7mm is 87.5 %, while all large-sized springs with a medium diameter of 35 ~ 37mm are unqualified, indicating that large-sized springs are subjected to higher loads for a long time and are prone to stress accumulation[8],resulting in structural deformation ;

3.2.3. The Relationship Between Service Life and Performance

The average verticality of the spring within 5 years of service is 3mm, which is more than 3 times that of the new spring, indicating that the performance degradation of the spring increases significantly with the service life.

3.2.4. Stiffness Stability

The coefficient of variation of the spring stiffness coefficient that meets the II-level accuracy is 10 %. For example, the maximum deviation of the spring stiffness of Wantong 's regulator in 2007 is 15.2 %, which cannot meet the requirements of voltage regulation.

In order to ensure the performance and safety of the regulator, it is necessary to strictly eliminate the springs with unqualified accuracy to avoid their adverse effects on the operation of the equipment. At the same time, the process control of spring manufacturing and inspection should be strengthened, and the verticality and end face quality of the spring should be guaranteed. It is suggested that regular precision inspection should be carried out for in-service springs, especially for springs that have been in service for more than 3 years. If the equipment has a high requirement for the stability of the output pressure, it is recommended to use a class I precision spring to meet the use requirements.

3.3. Analysis of Tensile and Compression Permanent Deformation of Rubber Diaphragm

The tensile properties and compressive permanent deformation of rubber diaphragm reflect its mechanical stability and elastic recovery ability, which are the key indicators of long-term service :

3.3.1. Tensile Properties

Table 3. Diaphragm tensile data results

Sample number	Tensile strength TS(MPa)	Breaking tenacity TSb(MPa)	Elongation at break E(%)
Diaphragm1	10.4684	10.4684	53.5563
Diaphragm2	6.41282	6.41282	121.598
Diaphragm3	12.1266	12.1266	1231.95
Diaphragm4	9.91679	9.91679	1147.14
Diaphragm5	9.88385	9.88385	1106.93
Diaphragm6	12.6528	12.6528	1158.89
Diaphragm7	9.92312	9.92312	1222.33
Diaphragm8	6.00790	6.00790	1116.29
Diaphragm9	5.17143	5.17143	1295.41

Chengdu Huatai RTZ-31 series diaphragm (factory from 2012 to 2013) performed best, with tensile strength of 12.13 ~ 12.65MPa and elongation at break of 1106.93 % ~ 1231.95 %, which was much higher than the requirements of GB / T 35529-2017 ' urban gas regulator rubber diaphragm ' with tensile strength ≥ 5MPa and elongation at break ≥ 100 % '. Although the tensile strength of the diaphragm produced by Fisher Jiuan in 2011 reached the standard (10.47MPa), the elongation at break was only 53.56 %, the brittleness of rubber[9]increased, and cracks were easy to occur after long-term use.

3.3.2. Compression Permanent Deformation

The compression permanent deformation rate of the diaphragm manufactured by Leshan Chuantian in 2019 is only 3.2 %, the elastic recovery ability is strong, and the rubber crosslinking[10]structure is stable ; in 2007, the permanent deformation rate of Wantong diaphragm was 18.5 %. After long-term compression, the initial height could not be restored, and the risk of sealing performance degradation was high, which needed to be replaced in time.

4. Conclusion

The performance of the core components of the old gas regulator is closely related to the brand and service life. The rubber diaphragms of Leshan Chuantian (2019) and Hebei Ruixing (2018) have the best gas resistance. The mechanical properties of Chengdu Huatai RTZ-31 series diaphragms are outstanding, and the qualified rate of small size spring with a diameter of about 9.7 mm is high. The spring is the weak link of the old regulator. The qualified rate of grade II accuracy is only 19.5 %. The verticality overrun is the main problem. The performance degradation of large-size spring and spring in service for more than 10 years is more significant. Rubber diaphragms that have been in service for more than 14 years generally have performance degradation, which is manifested by a decrease in gas resistance and an increase in compression permanent deformation rate, which needs to be included in the key monitoring and replacement range.

5. Discussion

Combined with the experimental results, the maintenance suggestions of the old regulator are put forward : first, the components with obvious performance degradation and more than 14 years of service should be replaced first, such as the diaphragm and spring of Wantong regulator in 2007 and Jensen regulator in 2007 ; the second is to monitor the compression permanent deformation of the diaphragm and the verticality of the spring for the regulator that has been in service for 10 to 14 years. If the compression permanent deformation rate exceeds 10 % and the verticality exceeds 3mm, it should be replaced in time. The third is to establish the core component ledger, record the brand, factory year and test data, and realize the whole life cycle management ; the fourth is to formulate a special inspection plan for large-size springs (middle diameter > 30mm), and carry out accuracy and stiffness tests every 3 years to avoid voltage regulation faults caused by spring failure.

The research results directly provide a quantitative basis for the operation and maintenance of the company 's old regulators : it is clear that the diaphragm 's ' mass change rate of 15 % ', the spring 's ' verticality > 3mm, and the stiffness fluctuation exceeds 10 % ' are immediate replacement thresholds, which can effectively reduce safety risks and optimize operation and maintenance costs.

Limited to the scope of the study, the component degradation model can be further improved by combining the old regulator data of different climate zones and different operating loads. At the same time, the remaining life prediction research of core components can be carried out to provide more accurate technical support for the ' condition-based maintenance ' of gas

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enterprises and help the long-term stable operation of urban gas transmission and distribution systems.

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