Study on typical metal fatigue failure of circuit breaker operating mechanism unit

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Abstract. Circuit breaker operating mechanism unit endure alternating stress during divide-shut brake operation, and metal components frequently appear fatigue failure. In the paper, the common failure features of energy storage spring fracture, shaft sleeve cracking, energy storage connecting bolt cracking were studied. Depending on this situation, macroscopic examination, metallographic examination, scanning electron microscope were applied. The results indicated that the metal components fatigue failure were mainly caused by bad material and improper installation. Technical supervision suggestion were also proposed to perfect the construction acceptance and operations management process.

1. Introduction
Along with the social economy development, especially the construction accelerating of ultra-high voltage transmission line, the stability operation of network became more and more important. However, good stability of circuit breakers is the key to electric power system orderly operation[1-3]. Operation mechanism works as the driver of circuit breaker closing/opening, which turning on/off circuits of normal/abnormal current due to operating instructions. The mechanism components endure hundreds of repeated stress owing to repetitiveness of divide-shut operation. As a result, some parts and components are prone to fail during cycling repeated stress[4-6]. In this paper, fatigue failure of circuit breaker energy storage spring, operating mechanism collar and connecting bolt were taken as cases analyzing the fatigue characteristics and failure cause, in order to provide technical support for operational maintenance and technical supervision.

2. Experimental section
All the failed circuit breaker operating mechanism unit were collected from substations in service. The morphologies and structures of the samples were analyzed by metallurgical microscopy(Zeiss microscope) and field emission scanning electron microscope (FE-SEM). FESEM characterization was performed on a JSM-7600F.

3. Results and discussion

3.1. Operating mechanism spring
Operating mechanism spring in some circuit breaker of 110kV substation once failed in September 2017. The circuit breaker was produced in 2007 in which the spring were consisted of 60Si2CrA steel. Macroscopic examination illustrated that the operating mechanism spring is classified as cylindroid helical-coil extension spring which is badly rusted especially in the interfaces of upper and lower
round steel. The fracture location was in the middle of spring, as displayed in Fig.1. The fracture surface was composed of 3 planes from top to bottom which covered by yellow rust. As illustrated in Fig.2, the 2 planes in the upper part and lower part were comparatively small which were also perpendicular to the surface of spring periphery (serious corrosion section). The fatigue crack grow along the middle surface which is much larger than the both ends. The fracture showed evident characteristic of brittle rupture and no signs of plastic deformation were observed.

![Figure 1. Macroscopic feature of cracked spring.](image1.png)  ![Figure 2. Fracture appearance of spring.](image2.png)

Hardness measurement showed that the hardness of spring is 50HRC. However, the hardness of cracked spring was higher than the standard range which ranged from 41.5 to 48.0 Rockwell according to the GB/T1239.4-1989 standard. Fracture of spring was further analyzed by SEM which result was displayed in Fig.3. In spite of the fracture surface being covered by oxidation product, the integunular fracture appearance and fatigue crack propagation path were also observed, as illustrated in Fig.3.

It turned out that spring steel mainly bears shear stress during its working via force analysis. And the maximum bearing positions were the upper and lower surfaces which also working as contact surface. In this sense, the upper and lower surfaces cracked spring seriously corroded which also had low plasticity. In addition, the spring possess high notch sensitivity as being made of medium high carbon steel. In hence, small cracks and defects firstly emerge in corrosion pit of spring contact surface which developed into crack initiation of spring steel with notch sensitivity under stress. The spring fractured in fatigue under repeated stress conditions.

![Figure 3. SEM picture of spring fracture.](image3.png)

3.2. Mechanism shaft sleeve
Mechanism shaft sleeve in some circuit breaker of 220kV substation once failed in April 2014 which put into operation in 2010. The circuit breaker was type LW29-126T/3150-31.5 which the mechanism
shaft sleeve was composed of GCr15 steel according to GB/T18254-2002 standard. As is illustrated in Fig.4, the fracture of cracked shaft sleeve exhibited light grey fault plane with fatigue cracks. To further check the inner surface cracks of shaft sleeve, the penetrant testing was carried out on inner surface of cracked sample. It turned out that the inner surface of shaft sleeve was covered by dense microscopic cracks as a large number of red lines highlighting on white ground, which was showed in Fig.5.

GCr15 steel was classified as high-carbon chromium bearing steel which possessed high brittleness and notch sensitivity. The hardness of GCr15 steel should be no less than 60HRC according to GB/T18254-2002 standard. The balls in mechanism shaft sleeve contacted directly with inner surface of shaft sleeve during operation process of circuit breaker. Surface contact fatigue and dense microscopic cracks occurred on inner surface owing to comparatively large stress. The antifatigue ability of shaft sleeve was unceasingly eliminated during service process which resulted in the fracture of shaft sleeve.

3.3. Energy storage connecting bolt

The energy storage connecting bolt of A-phase in some circuit breaker of 220kV substation once failed in August 2013 which put into operation in 2009. Failure took place at the bottom of bolt with broken part left in the ratchet. In addition, eccentric pressing pattern of thrust bearing spacer could be observed on surface of ratchet and were also located in off-centered position of inside screw, which was displayed in Fig.6.

The connecting bolt of circuit breaker with model of M24 type consisted of 42CrMo steel. Circular fine crest lines with gradually increasing striation distance from outside to inside could be observed on fracture using stereomicroscope. The fault plane exhibited fatigue crack propagation features with dark middle area which could be considered as brittle fracture, as is showed in Fig.7.
The physical and chemical test of cracked energy storage connecting bolt was carried out. The results indicated that the composition of bolt was in accordance with the requirements of 42CrMo steel in GB/T 3077-1999 standard. However, the brinell hardness of cracked sample was 280 HB which slightly exceeded the design drawing requirement. The metallographic microstructure was mixture of tempered martensite, pearlite and granular ferrite which was quite different from the Tempered sorbite of 42CrMo steel with modified treatment, as showed in Fig.8.

It could be reasonably inferred that the connecting bolt was wrongly assembled from the eccentric pressing pattern on the thrust bearing spacer of ratchet. In this condition, thrust bearing spacer was below the shaft sleeve leading to unsuccessful coupling action of oblique spiral surface and ratchet. As a result, the bottom of bolt was subjected to large impact and bending moment stress. The bolt was under low cycle fatigue concerning about short times of circuit breaker divide-shut brake operation during its service life leading to early low cycle fatigue fracture finally.

4. Conclusions
In consideration of repeated divide-shut brake operation, the energy storage spring, shaft sleeve and energy storage connecting bolt of circuit breaker were always in the fatigue condition which some fatigue failure would happen to some metal parts when encountering improper material selection, poor material or improper installation technology. Based on the above problems about circuit breaker, construction acceptance should be more focused on especially the connecting bolt checking, operation and maintenance management of circuit breaker, specific ambient humidity control and periodical inspection of metal parts in mechanism box. In this way, breaker failure even personal injury accident caused by corrosion pit, material imperfections and improper installation process could be effectively avoided.

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