Study on Failure Mechanism of Throttling Ring Based on Spectral Test Analysis Technique

Kaibo Cui\textsuperscript{1,}\textsuperscript{*}, Yezun Sun\textsuperscript{2,}, Mingzhe Zhang\textsuperscript{1,}\textsuperscript{b} and Zhenggang Wen\textsuperscript{3,}\textsuperscript{c}

\textsuperscript{1}Shijiazhuang Campus of Army Engineering University, Shijiazhuang, 050003, China
\textsuperscript{2}Unit 32382, Beijing, 100071, China
\textsuperscript{3}Unit 31691, Jiamusi, 154000, China

*Corresponding author e-mail: 461149680@qq.com, \textsuperscript{a}cuikaibo1985@sina.com, \textsuperscript{b}1281064883@qq.com, \textsuperscript{c}bc_wen@163.com

Abstract. The throttling ring plays an important role in the normal performance of the gun. The inner diameter of the throttling ring directly affects the gun's recoil stress law and recoil motion parameters. It is of great significance to study the failure mode and failure mechanism. By means of spectral test and analysis technology, wear particle analyzer and ICP-MS and FAAS method are used to test and analyze the content of abrasive particles and ions in the use environment of throttling ring, and to study and determine the failure mechanism of throttling ring.

1. Introduction
In order to clarify the failure mechanism of the throttling ring of the gun's retractable machine, the retractable fluid, the working medium in the operating environment, was studied. Firstly, an automatic wear particle analyzer (SpectroLNF Q200) based on CCD rapid imaging and spectral identification technology is used to identify the metal particles, bubbles, water droplets and other impurities contained in the old samples of the standing liquid for morphology and quantity statistics. [1] Secondly, ICP-MS and FAAS spectroscopy were used to test the content of metal ions in the old samples of new and new standing-back solutions respectively, and the comparative analysis was carried out. Finally, based on the particle information and metal ion content in the oil, the causes of the failure of the throttling ring were studied, and the failure mechanism of the throttling ring was gradually clarified.

2. Statistical identification of metal particles and bubbles
The type, size, morphology and quantity of particles in the old sample of standing back liquid were analyzed by SpectroLNF Q200 automatic wear particle analyzer. The particle analyzer can identify the particles in the oil as cutting wear particles, fatigue wear particles, sliding wear particles and non-metallic impurities through the neural network technology. It can count the particles of 5μm~100μm, and provide image recognition of particles greater than 20 μm.
As can be seen from the particle recognition image in Fig.1, in addition to a large number of cutting wear particles, fatigue wear particles and sliding wear particles, there are also a small number of non-metallic impurities, bubbles and water droplets in the old sample of standing recession solution. To recoil to statistics show that the number of different size particles in liquid (Fig.2), back in the diameter of the particles in liquid, the greater the particle content is less, such as 5μm ~ 15μm diameter of particle number is 21963 / ml, and a diameter of 50 microns to 100 microns particle number is 72 / ml, but overall, particle diameter and particle content does not present a linear regressive relationship between. The statistics of different types of wear particles in the old sample of the standing back liquid showed (Fig.3) that the number of cutting wear particles was the largest, with the content of 12342 /ml, followed by the number of sliding wear particles, and the number of fatigue wear particles was relatively small, with the number of 6587 /ml. Therefore, the metal particles in the old sample are mainly the cutting wear particles and sliding wear particles. Compared with metal wear particles, the content of non-metallic impurities is very small, only 274 /ml. The statistics of bubbles in the standing-back liquid (Fig.4) showed that the total content of bubbles was very small. Among the bubbles in the recognizable range of 5μm~100 μm, those with diameters of 20μm~30μm had the largest number of bubbles, with the content of 24 /ml.
In order to verify whether there are particles and bubbles ≥100μm in the old sample of the standing liquid, the old sample of the standing liquid was observed by optical microscope and its size was measured by a scale. The observation results are shown in Fig.5.

As can be seen from the figure, a small number of metal particles with diameters ranging from 100μm to 800μm are randomly distributed in the old sample of standing liquid, as shown in Fig.5(a), Fig.5(b) and Fig.5(c). In addition, a few bubbles were also found in the standing-back solution under the optical microscope, with diameters ranging from 10μm to 110μm, as shown in Fig.5(d).
3. Formation mechanism of erosion wear and cavitation failure

3.1. Erosion and wear of metal particles
According to the measurement data of the automatic wear particle analyzer and the image observed by the optical microscope, it can be concluded that the metal particles, non-metal impurities and bubbles objectively exist in the recoiling liquid during the use of the gun, among which the number of metal particles is the largest. The composition of metal particles is determined by the material composition of the flow passage part in the retraction machine. It can be seen from the structure composition of the retractor that the components of the overcurrent components in the retractor show the characteristic of "more steel and less copper". [2] Therefore, most of the metal particles in the stand-off liquid come from the steel part in the stand-off liquid, a small part from the copper part, and a few metal particles and non-metal impurities are mixed into the stand-off liquid from the outside when the stand-off liquid is working.

When the retraction and reentry of the retraction machine are rapid, the retraction fluid with metal particles in the high-speed flow will have a severe impact on the inner diameter surface of the throttling ring, resulting in erosion and wear, resulting in elastic-plastic deformation and impact damage of the material surface tissue, and finally peeling off from the matrix in the form of cutting. Wear marks, stripes or furrows will appear on the surface of the material, resulting in mass loss.

3.2. Cavitation destruction of bubbles in oil
At the same time when the throttling ring is subjected to erosion and wear, the bubbles generated or precipitated in the standing liquid will cause cavitation damage to the inner diameter of the throttling ring. Cavitation refers to the phenomenon that cavitation damages the metal surface in contact with the fluid under the condition of high-speed flow and pressure change. [3] Cavitation damage usually occurs on the surface of overcurrent components such as turbine blades, pump parts and ship propellers. During the use of artillery, a certain number of bubbles will be formed or precipitated outside the standing liquid, and the liquid flow velocity and liquid pressure near the liquid flow hole formed by the throttling ring and the variable diameter control rod will be suddenly changed, which objectively provides the external conditions for the generation of cavitation. Therefore, when the gun fire at high speed, the throttling ring will be cavitation damage. However, the impact strength of the bubbles is relatively weak compared with the erosion wear of metal particles, and the damage degree of the throttling ring caused by cavitation failure is limited.

4. Electrochemical corrosion mechanism of throttling ring
According to the physical and chemical properties of the standing-back solution, the PH value of No. 4 standing-back solution is between 8.2 and 8.5, which belongs to the weak alkaline solution. According to the analysis of metal corrosion theory, it is found that the alkaline environment is favorable to the protection of steel but unfavorable to copper, and the acidic environment is favorable to the protection of copper but unfavorable to steel. At present, the spare parts of the gun in active service are characterized by "more steel and less copper". Therefore, the slightly alkaline standing liquid mainly plays a role of steel protection. In the environment where standing liquid is the electrolyte solution, the electrochemical reaction dominated by oxygen corrosion will occur in the copper flowing parts. The cathodic reduction reaction of oxygen corrosion under different PH values is as follows:

\[ O_2 + 2H_2O + 4e^- \rightarrow 4OH^- \] (neutral or alkaline) \hspace{1cm} (1)

\[ O_2 + 4H^- + 4e^- \rightarrow 2H_2O \] (acid medium) \hspace{1cm} (2)

In the standing-back machine, the cathodic process of electrochemical corrosion will conduct oxygen reduction reaction according to formula (1). The copper, zinc, aluminum and other elements in the aluminum brass throttling ring will undergo oxidation. With the most abundant copper element, for
example, under the action of copper in oxygen, a small number of complete oxidation happens, generate bivalent copper salt, in addition, there are a large part of the first generation will be a price of copper salt, which in turn into bivalent copper oxide salt, constitute a Cu$^{2+}$ ions, there are a few will be hydrolyzed to form cuprous oxide (commonly known as copper powder), specific response as shown in formula (3) to formula (5).

$$\text{Cu} \rightarrow \text{Cu}^{2+} + 2e^- \quad \text{(complete oxidation)} \quad (3)$$

$$\text{Cu} \rightarrow \text{Cu}^+ + e^- \quad \text{(incomplete oxidation)} \quad (4)$$

$$2\text{Cu}^+ + 2\text{H}_2\text{O} \rightarrow 2\text{CuOH} + 2\text{H}^+ \rightarrow \text{Cu}_2\text{O} \downarrow + \text{H}_2\text{O} \quad (5)$$

As can be seen from the above, cavitation will seriously damage the protective film of the metal surface. Under the condition of high speed flow of the standing liquid and rapid change of chamber pressure, cavitation will aggravate the electrochemical corrosion degree, and cave corrosion will be formed in the pitting and pits formed by cavitation.

5. Test and analysis of metal ion content

For validation throttling ring and recoil fluid will happen in the actual contact reaction, electrochemical corrosion on aluminum brass HAL66-6-3-2 alloy contains metal elements, using the method of spectral analysis of recoil corresponding metal ion content in the fluid to carry on the quantitative detection, through the recoil fluid collection and recoil fluid old sample within the same metal ion content of comparison and analysis, test whether restraint ring electrochemical corrosion reaction. ICP-MS method was used to detect the new stand-off liquid (marked as No. 0) and FAAS method was used to detect the old stand-off liquid (marked as No. 1~5) collected from the gun to be repaired. [4] [5]

As can be seen from the metal ion content data measured in Table 1, compared with the new standing liquid, the content of Cu, Zn, Al, Fe, Mn and other elements in the collected old samples of standing liquid all increased, in which the content of Cu, Zn, Al and other elements increased significantly, while the content of Fe and Mn ions increased slightly. Because each gun's projectile history, maintenance times and maintenance cycle are different, so the content of metal ions in the old sample of the standing liquid is not the same, sometimes even a big difference. Characteristic elements such as Cu, zinc, and Al are mainly distributed in recoil machine inner restraint ring and cylinder aluminum brass parts, so the above test results show that aluminum brass restraint ring by the electrochemical corrosion effect, resulted in moderation on the part of the metal elements oxidation reaction happened in different degrees, with a final state of ions dissolved in recoil fluid.

| sample number | Cu   | Zinc | Al   | Fe   | Mn   |
|---------------|------|------|------|------|------|
| 0             | 0.0591 | 0.1070 | 0.501 | 0.4930 | 0.0145 |
| 1             | 2.3679 | 1.4569 | 2.527 | 1.4828 | 0.0736 |
| 2             | 6.1597 | 3.6236 | 2.869 | 0.9122 | 0.0864 |
| 3             | 5.9760 | 5.1888 | 3.122 | 1.6118 | 0.1245 |
| 4             | 2.0969 | 3.0517 | 1.572 | 0.8150 | 0.0903 |
| 5             | 3.2554 | 2.8831 | 2.103 | 1.1218 | 0.0652 |

6. Conclusion

The following conclusions can be drawn through the wear particle identification analysis, optical microscope observation and spectral test comparison of the standing liquid: (1) the standing liquid contains a large number of metal particles with different shapes and sizes, as well as a small amount of
non-metallic impurities, bubbles and water droplets; (2) the larger the diameter of the metal particles in the standing liquid, the less the particle content, but there is no linear decreasing rule, the metal particles contained in the standing liquid will have erosion and wear effect on the throttling ring; (3) there is no specific rule between the bubble content and the bubble diameter in the standing liquid. The number of bubbles with the diameter between 20μm and 30μm is the largest. As the overall content of bubbles is very small, the damage degree of cavitation to the throttling ring is relatively weak; (4) the standing-back solution is weak alkaline and neutral solution, and corrosion inhibitor is added to the formula. The increase and decrease of metal ion content caused by electrochemical corrosion is only PPM level, so the influence of electrochemical corrosion on the throttling ring is small.

References
[1] L.Hong, W.T.Wen, Y.T.Shu, et al. Application of wear particle analysis technology in engine wear fault monitoring [J]. Contemporary chemical industry, 2013, 42 (4): 529-532.
[2] C.Xu, Y.P.wang. Dynamics of artillery and automatic weapons [M]. Beijing: Beijing institute of technology press, 2006.
[3] W.W.Meng. Design and simulation of small water flow energy power generation device [D]. Wuhan: master thesis of wuhan university of technology, 2012.
[4] G.J.Gao, Y.F.Li, S.Y.Feng. Determination of iron, cobalt, manganese and nickel in synthetic diamond by inductively coupled plasma atomic emission spectrometry [J]. Analytical chemistry, 2014, 42 (3): 457-458.
[5] C.Liu. Determination of nickel in sediment by microwave digestion-flame atomic absorption spectrometry [J]. Agriculture &Technology, 2014, 32 (4): 248-256.