Research and Application of Locking Strip for Inter-Hexagon Screw in Main Pump for Nuclear Power Station

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Abstract—The loosening of inter-hexagonal screws connecting internal parts in main pump for nuclear power station causes some nuclear safety problem due to medium erosion at present. Aim at the problem, a special locking strip for inter-hexagonal screws is put forward and the structure of the locking strip, the bending process and the forming die of the locking strip are designed and calculated in this paper. Furthermore, the fastening tool of the locking strip is designed, and the feasibility of the locking strip is verified in the experiment so as to improve the anti-loosening reliability. The locking strip for inter-hexagonal bolts can be widely applied to the locking and fastening industry application fields.

1. Introduction
The reliable operation of main pump for nuclear power station is closely related to the safety of nuclear power plant. The inter-hexagonal screws are used as the important connection components between the internal parts in the radioactive medium. Due to long maintenance cycle, such as about 30 years of the maintenance cycle in the nuclear pump station and even its repaired cycle (60 years) of the main pump once, the inter-hexagonal screws have been the key connection parts in long-term vibration and continuous scouring of fluid in long-term run [1]. The anti-loosing measures about these inter-hexagonal screws commonly have high failure rate and low reliability for the severe influence of fluid scouring and other uncertain factors [2]. After long-term run, these inter-hexagonal screws are prone to loose, fall off or even failure, which will bring serious danger to the safety in nuclear pump station. Therefore, a kind of special locking strip with high reliability is needed to ensure that these inter-hexagonal screws are not loose, which will improve the reliability in nuclear pump and ensure the safety in operation..

2. Material and Methods
2.1. Material
The 06Cr19Ni10 blank investigated in this study is obtained by wire cutting from cold rolled sheet stock with the thickness of 0.5-1.5 mm and the nominal chemical composition given in Table.1". 
Table 1: Chemical composition of the 06Cr19Ni10 by Optical Emission Spectrometry (OES)

| Element | C | Si | Mn | P | S | Ni | Cr |
|---------|---|----|----|---|---|----|----|
| wt%     |   |    |    |   |   |    |    |
| Fe      | 0.08 | 0.75 | 2.00 | 0.045 | 0.03 | 8.00-10.5 | 18.0-20.0 |

2.2. Design requirements for the locking strip

The locking strip obtained is disposable. The structure is shown in Figure 1. The bending radius R of the strip is designed by ProE sheet metal bending characteristics to ensure that the maximum length of locking strip after bending does not exceed the installation aperture [3-4]. The material of the locking strip is made of austenitic stainless steel with high corrosion resistance and low hardness. The material properties can meet the mechanical requirements of nuclear pump material, such as prohibiting the use of materials containing low melting point elements.

Thickness of the locking strip should be selected according to its size, which 0.5-1.5 mm thick can be recommended within M30. The thickness can be taken larger about larger size. If the locking strip is too thick, strength and springback properties are serious after bending, which disassembling can be relatively difficult. If the locking strip is too thin, installation strength is not enough and it will affect the locking reliability.

The dimension L (as shown in Figure 1) of the locking strip deformed should be less than 2-3 mm [5-6] of the installation aperture; the diameter D of the central circular hole should be less than 2-5 mm of the diameter of the inner tangential circle of inter-hexagonal screw; The locking strip r should be matched with the arc groove r machining the installation hole.

![Figure 1: Structure and installation hole diagram of special locking strip](image)

2.3. Design requirements for the locking strip

The locking strip can be formed in two steps, which firstly the blank of the unfolded strip can be stamped and then the blank can be bented. The unfolded strip can be obtained by wire cutting or blanking and punching compound die. For small batch production, machining method of wire cutting is recommended and blanking and punching compound die method only will be used for large batch production.

Bending can be achieved by continuously pulling materials from non-deformed zone outside the die into the die (deformed zone) [7]. From the locking strip structure diagram, it can be seen that bending depth of the locking strip is small, therefore it can meet the requirements by one-step bending. The scheme of bending die is shown in Figure 2.
The influence of springback radius after bending should be considered when the corner radius of punch and die is designed. For upper and lower die base, the round diagonal guide pillar with GB/T 2855-2008 is adopted. The upper die base is connected with the slider of the press through the revolving die shank with JB/T7646.2-2008. The lower die base is fixed on the platform of the press by pressing plate and bolt. The sliding structure for guide pillar and guide sleeve is used according to GB/T 2861.1-2008. The guide pillar is installed in the lower die base and the guide sleeve is installed in the upper die base. The H7/r6 interference fit is applied between guide pillar and guide sleeve. In order to prevent the misaligning of the locking strip during stamping process, the middle hole of the strip can be stamped and the center of the locking strip can be located by the special pins and springs.

3. RESULTS and DISCUSSION

3.1. Calculation of Bending Force

The bending process of the locking strip can be approximately considered as the middle arc bending and the ear bending as shown in Figure. 3. The empirical formula is usually used to estimate the bending force in practice. The bending force of the locking strip can be approximately considered as the combined force of two bending processes.

\[
F_{\text{bending}} = F_1 + F_2
\]  

Figure.3 Simplification of bending process for locking strip

The bending force of the middle arc is calculated by the following formula.

\[
F_1 = 1.42 \frac{r^2 l}{V} \sigma_y
\]
where $t$ is sheet thickness (mm), $l$ is sheet bending length (mm), $V$ is opening length of die and $\sigma_b$ is tensile strength of material (MPa). The tensile strength of the material can be taken as 520 MPa.

The bending in ear region is equivalent to fixing the middle arc and bending ear arc at a certain angle when the pressing. The bending force in ear region of the strip is calculated according to the following empirical formula.

$$F_2 = \frac{M}{L}$$

(3)

$$M = \frac{1}{6} [Br^2 \sigma_b (1.3 + 0.8\epsilon_b)]$$

(4)

where $M$ is bending moment (N∙m), $L$ is the arm (mm), $B$ is sheet width (mm), $t$ is sheet thickness (mm), $\sigma_b$ is tensile strength of material (MPa), $\epsilon_b$ is elongation percentage ($\%$). Here, the tensile strength of the material can be taken as 520 MPa. Elongation percentage can be taken as 40%.

3.2. Bending Springback

When the bending radius of locking strip is large, there is the occurrence of springback after bending [8-9]. If the springback is large, the size of locking strip will be larger than the installation aperture, which makes it impossible for installing the strips. Therefore, the springback should be taken into account in die design and it should be calculated by the following formula [10].

$$R = \frac{R'}{1 + \frac{3}{E \cdot t} \frac{\sigma_s}{\epsilon_s} R'}$$

(5)

where $R$ is round corner radius before springback (mm), $t$ is sheet thickness (mm), $E$ is elastic modulus of bending materials (MPa), $R'$ is round corner radius after springback (mm) and $\sigma_s$ is yield limit of bending materials (MPa). Here, elastic modulus of bending materials can be taken as 194.020GPa. Yield limit of bending materials can be taken as 209MPa.

3.3. Design of disassembly and assembly tool for locking strip

- Fastening tool

The fastening tool shown in Figure 4 is composed of a punch and a fastening nut connected by threads. The head of the punch looks like a small cap shape, which punches into the central hole of the locking strip. Its cross-section profile is hexagonal. The dimension of hexagonal profile is slightly smaller than the dimension of inter-hexagonal screw minus two thicknesses of the strip. When the locking strip is installed, it is punched into the central hole of the inter-hexagonal screw with a punch. The surface of the punch is needed higher hardness. The hardness of the hexagonal head is about 50HRC by surface quenching. After the locking strip installation, the punch is withdrawn by loosening the fastening nut.

![Figure 4 Fastening tools](image)
Application of Fastening Tool

The inter-hexagonal screw is tightened according to the specified moment. The locking strip can be installed as following steps: firstly install the locking strip into the inter-hexagonal screw as tightening tool is tapped by hammer; secondly tighten the fastening nut; then withdraw the tightening tool. The installation schematic is shown in Figure.5

![Installation schematic diagram of strips](image)

1 Strip before installation  2 Fastening tool  3 Strip after installation

Test verification

The locking strips and disassembly tools corresponding to M16 screw are used for test verification. Its material is made of 304 stainless steels. It has a thickness of 0.5 mm, 0.7 mm and 1.0 mm, respectively. It is convenient and reliable to use disassembly tools in the test. For locking strips of different thickness, disassembly experiments are carried out. When stainless steel strips with the thickness of 0.5mm, 0.7mm and 1.0mm are used, the disassembly and assembly forces are 1950N, 2730N and 3900N, respectively. Therefore, it can be seen that with the increase of thickness, the greater disassembly and assembly force is used and there is the higher the locking reliability after installation. After repeated tests, the strip with the thickness of 0.7mm has the best locking reliability under the simulated condition of vibration and shock. Fig. 6 shows the relevant photographs of the test validation.

![Test verification of locking strip](image)

4. CONCLUSIONS

Aiming at the poor anti-loosening reliability of inter-hexagonal screws in nuclear main pump, a special locking strip is put forward. Its structure, forming process, die design, fasten and disassembly tool are designed and calculated. The following conclusions are drawn:

1. The locking strip is a disposal strip. The blank of the unfolded locking strip is formed by wire cutting and bending. The feasibility of the proposed method is verified by forming experiments.

2. Through the research of fasten and disassembly test for the locking strip, it can be concluded that the head of the disassembly tool is easy to wear. In order to improve the service life, it is necessary to improve the surface hardness by heat treatment. At the same time, the thickness of the locking strip should be selected according to its size. The optimum thickness of the strip is determined to be 0.7mm.
(3) The disassembly of the locking strip is more complicated than that of the traditional strip, but it can ensure the anti-loosening reliability of the inter-hexagonal screw and improve the reliability of the nuclear pump operation from the reviews of safety. At the same time, it can be widely applied to the locking and fastening industry application fields.

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REFERENCES
[1] Mingguang Zheng, Jinquan Yan, Jun Shentu, et al, “The General Design and Technology Innovations of CAP1400”, Engineering, 2016, pp. 97-102
[2] Yang jiwei, Wang xuedong, Liu lian, “Research and development on pump shell casting of CAP1400 Nuclear Main Pump”, Foundry Technology, 2018, pp.812-814.
[3] Zheng Kehuang, Practical Manual for Stamping Die Design. Beijing: Machinery Industry Press, 2007.
[4] Trzepieciniski, Tomasz, Malinowski, Tomasz, Pieja, Tomasz, “Experimental and numerical analysis of industrial warm forming of stainless steel sheet”, Journal of Manufacturing Processes, 2017, pp. 532-540.
[5] Liu Jin, Kong Fei, Liu Hongdao, “Calculation of free bending force of plate bending machine”, China Metalforming Equipment & Manufacturing Technology, 2011, pp. 36-37.
[6] Ma Funan, “Discussion on Suitable Conditions for Calculating Formula of Bending Springback”, Compressor Blower & Fan Technology, 1997, pp. 31-32.
[7] Guan yingping, Li hongbo, Wang fengqin, “Discussion on the Calculation Method of Minimum Relative Bending Radius of Plate Bending”, Metal forming process. 2003, pp. 52-53.
[8] Chen Wei, Chen Honghui, Xie Jun, et al, “Research on die face design based on springback compensation”, Forging & Stamping Technology, 2008, pp. 86-90.
[9] Xie Hui, Pan Zhihong, Jiang Haomin, et al, “Research on springback compensation based on fully cycle simulation of high strength steel”, Journal of Plasticity Engineering, 2012, pp. 72-77.
[10] Narayanasamy R, Padmanabhan P, “Modeling of springback on air bending process of interstitial free steel sheet using multiple regression analysis”. International Journal of Interactive Design and Manufacturing 2009, pp. 25-33.