Design and Analysis of A Novel Handcuffs with Two Locks

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Abstract. The locking mechanism of raditional handcuff ring is simple with lower reliability. A noval handcuffs was designed. Besides the traditional ratchet locking structure, a magnetic locking structure was added to ensure the security. The appearence and structure of the novel handcuffs were designed and validated with FEM analysis. Meanwhile, the handcuffs were smoothly contoured.

1. Introduction

Handcuffs are one of the most important police equipment. The commonly used handcuffs at present were invented in 1980s having simple structure and operation [1]. However, the simple unlocking of the traditional handcuffs make it possible for suspects to escape in a short time and many cases have happend [2]. In the current imformation era, it is a necessary work to update the structure and fuction of handcuffs and therefore the current study.

2. Mechanical structure

The mechanical structure of the newly designed handcuffs were illustrated as Fig.1. As can be seen, the main structure is similar to the commonly used version. A main ring is fixed and hinged with a ratchet ring. The two rings are locked together through a ratchet mechanism, which is the same with that of the traditional handcuffs. The main difference in structure between the new handcuffs and the traditional one was the newly designed magnetic locking mechanism. As shown in Fig.1, a hinge mechanism is used to connect the main ring with the ratchet ring. Meanwhile, the hinge mechanism acts as a second lock of the handcuffs and named as magnetic lock. When locking the handcuffs, the operation is indentical to the traditonal way. Whereas, when unlocing, the manetic lock should be opened firstly with a special strong magetical key before opening the ratchet lock. Therefore, there are two steps when unlocking the handcuffs. In addition, a chip box is newly designed in the handcuffs with purpose to advance the intelligence and informatization of the handcuffs, such as location, communication and identification, etc.
Beside the improvement in mechanical mechanism, some other structure modifications were also made to ensure the mechanical properties of the novel handcuffs. An arched reinforced rib was added to the ratchet ring to improve the strength. Besides, a slot track was designed inside the handcuffs to realize the smooth sliding of the ratchet ring. The main parameters of the designed handcuffs are listed in Table.1.

| Weight /g | Total length /mm | Max locking size /mm | Min locking size /mm | Tooth number |
|----------|------------------|----------------------|----------------------|--------------|
| 200      | 29500            | 81                   | 45                   | 20           |

3. Material and appearance design
The mostly used material for handcuffs is carbon steel with surface nickel plating. In order to reduce the weight of handcuffs, a sort of poly ether ether ketone (PEEK) material was chosen as the body material of new handcuffs. The material of lock cylinder remains carbon steel with nickel plating.

Fig.2 shows the appearances of the handcuffs from the front and back views, respectively. The two handcuff rings were smoothly contoured. The ring surfaces were designed by space curves. All the joints are free rotation hinges together with arc transition.

4. Strength and durability analysis
Finite Element Analysis (FEM) method was utilized to investigate the strength and fatigue behavior of the designed handcuff.
The longitudinal tensile strength analysis was performed on a single handcuff ring. Fig.3 illustrates the constraint model, where the longitudinal force was set as 3000N.

![Fig 3. The constraint model for longitudinal tensile strength analysis.](image)

Fig.4 shows the deformation and stress contours of a handcuff ring when being stretched under a force of 3000N. Fig.5 demonstrates the deformation and stress situation of the hinge that connecting the two handcuff rings. Combined the two figures, it can be observed that the hinge bore the maximum longitudinal tensile force. According to analysis results, the maximum deformation measurements of the handcuff ring was less than 0.9mm, and the maximum deformation of the hinge was less than 0.7mm. There was no stress concentration, indicating a reasonable stress distribution.

![Fig 4. The deformation (left) and stress contours (right) of handcuff in longitudinal tensile test.](image)

![Fig 5. The deformation (left) and stress contours (right) of handcuff in longitudinal tensile test.](image)
Fig. 6 shows the constraint model of transverse tensile analysis, where point A is fixed and a transverse force of 3000N was applied at point B.

![Fig 6. The constraint model for longitudinal tensile strength analysis.](image)

Fig. 7 shows the deformation and stress contours of a handcuff ring in transverse tensile test. Fig. 8 demonstrates the deformation and stress situation of the hinge. According to the results, the maximum deformation measurements of the handcuff ring was less than 0.01mm, the maximum deformation of the hinge was less than 0.002mm, and no stress concentration was found.

![Fig 7. The deformation (left) and stress contours (right) of handcuff in transverse tensile test](image)
Fig 8. The deformation (left) and stress contours (right) of handcuff in transverse tensile test.

The serving life is important to the application of handcuff. Fatigue strength, i.e. durability, was tested on a single handcuff ring. Fig. 9 shows the constraint model, where the ratchet handcuff ring was set to open and close 60000 times.

Fig 9. The constraint model fatigue analysis.

Fig 10. The calculation of safety factor.
Fig.10 shows the calculation of safety factor under 6000 times cycle. The result indicates that the
safety factor of the handcuff ring was stabled at 15, indicating good durability.

5. Conclusions
A novel handcuffs with high security was designed and analyzed. A special magnetic locking
mechanism was designed to increase the difficulty of unlocking of handcuffs. Meanwhile, the whole
structure and appearances of the handcuffs were optimized and contoured. Furthermore, the mechanical
properties of the handcuffs were analyzed by FEM method. The results approves the reasonability of
the new handcuffs.

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