Wear Analysis of a Low-Speed Diesel Engine Connecting Rod Based on Orthogonal Simulation Test

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Abstract. As con-rod is a critical component in an engine, its reliability overwhelmingly directly affects the performance of the whole diesel engine. The fretting wear of con-rod bushing mainly occurs on the contact surface with con-rod small end and con-rod small end cap. In the proposed study, the contact process of con-rod small end, con-rod small end cap and bushing under maximum combustion pressure condition was analyzed, and the distribution of contact pressure and friction stress was analyzed. Then the orthogonal simulation test was designed. According to the contact mechanics theory, the interference amount and friction coefficient of the contact surface were taken as the test factors, and the maximum contact pressure and friction stress under the maximum combustion pressure condition were taken as the objective functions. The influence of the test factors on the objective function was analyzed, and the most reasonable interference amount and friction coefficient were found, so as to slow down the fretting wear of the con-rod bushing.

1. Introduction
Con-rod is one of the essential moving parts of diesel engine [1-4]. It is one of the most important and critical components in an engine [1,5]. It is responsible for transferring the reciprocating motion to rotating motion [6]. Con-rod is subjected to many external forces [1]. As con-rod is a critical component in an engine, its reliability overwhelmingly directly affects the normal operation and performance of the whole diesel engine.

In the analysis of a number of applications finite element analysis (FEA) has been widely adopted [1]. This method is very useful because it reduces the time and energy spent in the laboratory and gives us very good and scientifically acceptable results. Both in the past and recent years, as an effective analysis method, a number of researchers have depended on FEA in their studies on con-rods [1-5].

The connecting rod is a very important part of the diesel engine. The efficiency of this important part affects the overall performance of the diesel engine. The material of the connecting rod is very important to its working efficiency, and the connecting rod design also affects its working performance. In order to improve the performance of the connecting rod, the stress and the deformation have been studied. Some scientists have studied the performance of the connecting rod with different materials. Others have
used different designs to study its performance. The connecting rod plays a very important role in transmitting the internal motion of the machine. The connecting rod is subject to many external forces. These external forces will certainly affect its performance and efficiency. Therefore, all external forces affecting the connecting rod must be studied. Designers must study all external forces that affect it and minimize their impact on the performance of the connecting rod. Because this external force acts on the connecting rod, wear is appeared and affect its performance. Sometimes the connecting rod needs to be replaced by another one. In the study of Helal et al. [1], the strength and fatigue of a low-speed diesel engine connecting rod were analyzed. 42CrMoA was used as material for connecting rod and fatigue limit of this material is 430-540MPa.

The wear of the connecting rod part is very dangerous to its performance. As the efficiency of this part affects the overall performance of the diesel engine.

In this study, the contact process of con-rod small end, con-rod small end cap and bushing under maximum combustion pressure condition is analyzed, and the distribution of contact pressure and friction stress is analyzed. Then the orthogonal simulation test is designed. The influence of the test factors on the objective function is analyzed, and the most reasonable interference amount and friction coefficient are found, so as to slow down the fretting wear of the con-rod bushing.

2. Materials and Methods

2.1. Materials

| Table 1 Material properties of diesel engine moving parts |
|----------------------------------------------------------|
| Material | Piston | Con-rod | Crankshaft |
|----------------|--------|----------|------------|
| Modulus of elasticity MPa | 2.1×10⁵ | 2.1×10⁵ | 2.1×10⁵ |
| Poisson's ratio | 0.3 | 0.3 | 0.3 |
| Density kg/m³ | 7850 | 7850 | 7850 |
| Strength limit σ₀ MPa | 980 | 980 | 980 |

2.2. Methods

It is better to study engineering applications in three dimensions than in two dimensions, because they provide good and accurate results. In the current study, the connecting rod 3-D model built. In order to build the connecting rod 3-D model, Creo 2.0 was used. The present problem model is shown in Fig. 1. For analysis, ANSYS, R. 19 was used in the current study.

![Figure 1 A Con-rod assembly model.](image-url)
Fig. 2 shows the con-rod model after meshing. The boundary conditions applied in this study is shown in Figure 3.

2.3. Orthogonal simulation test

Through the design of orthogonal simulation test, the influence of interference and friction coefficient on contact pressure and friction stress on the contact surface of bushing and con-rod can be explored to reflect the contact condition of bushing. The most appropriate interference and friction coefficient can be determined so as to optimize the fretting wear of con-rod bushing.

![Figure 2 The con-rod model](image1)

![Figure 3 The boundary conditions.](image2)
3. Results and Discussion
In the present study, the interference and friction coefficient were taken as test factors, and the maximum contact pressure and friction stress on the contact surface were taken as objective functions. The test scheme and calculation results are shown in Table 2.

Table 2 orthogonal simulation test scheme

| No. | Friction coefficient | Interference/mm | Contact pressure/MPa | Friction stress/MPa |
|-----|----------------------|-----------------|----------------------|--------------------|
| 1   | 0.15                 | 0.06            | 30.80                | 1.58               |
| 2   | 0.15                 | 0.07            | 32.28                | 1.36               |
| 3   | 0.15                 | 0.08            | 33.81                | 1.11               |
| 4   | 0.15                 | 0.09            | 34.33                | 1.09               |
| 5   | 0.15                 | 0.10            | 35.25                | 0.92               |
| 6   | 0.15                 | 0.11            | 36.18                | 0.85               |
| 7   | 0.16                 | 0.06            | 30.82                | 1.97               |
| 8   | 0.16                 | 0.07            | 32.31                | 1.91               |
| 9   | 0.16                 | 0.08            | 33.92                | 1.83               |
| 10  | 0.16                 | 0.09            | 34.63                | 1.74               |
| 11  | 0.16                 | 0.10            | 35.31                | 1.68               |
| 12  | 0.16                 | 0.11            | 36.34                | 1.52               |
| 13  | 0.17                 | 0.06            | 30.85                | 2.05               |
| 14  | 0.17                 | 0.07            | 32.38                | 1.96               |
| 15  | 0.17                 | 0.08            | 33.94                | 1.89               |
| 16  | 0.17                 | 0.09            | 34.79                | 1.76               |
| 17  | 0.17                 | 0.10            | 36.12                | 1.62               |
| 18  | 0.17                 | 0.11            | 36.73                | 1.50               |
| 19  | 0.18                 | 0.06            | 30.89                | 2.21               |
| 20  | 0.18                 | 0.07            | 32.40                | 2.45               |
| 21  | 0.18                 | 0.08            | 33.96                | 2.05               |
| 22  | 0.18                 | 0.09            | 34.72                | 1.95               |
| 23  | 0.18                 | 0.10            | 36.29                | 1.76               |
| 24  | 0.18                 | 0.11            | 36.93                | 1.54               |
| 25  | 0.19                 | 0.06            | 30.15                | 2.71               |
| 26  | 0.19                 | 0.07            | 30.83                | 2.62               |
| 27  | 0.19                 | 0.08            | 32.52                | 2.43               |
| 28  | 0.19                 | 0.09            | 33.27                | 2.31               |
| 29  | 0.19                 | 0.10            | 34.13                | 2.19               |
| 30  | 0.19                 | 0.11            | 35.25                | 2.05               |

4. Conclusion
The connecting rod is subject to many external forces. These external forces will certainly affect its performance and efficiency. Therefore, all external forces affecting the connecting rod must be studied. Designers must study all external forces that affect it and minimize their impact on the performance of the connecting rod. Because this external force acts on the connecting rod, wear is appeared and affect its performance.

In this study, the contact process of con-rod small end, con-rod small end cap and bushing under maximum combustion pressure condition was analyzed, and the distribution of contact pressure and friction stress was analyzed. Then the orthogonal simulation test was designed. Through the design of orthogonal simulation test, the influence of interference and friction coefficient on contact pressure and friction stress on the contact surface of bushing and con-rod can be explored to reflect the contact
condition of bushing. The most appropriate interference and friction coefficient can be determined so as to optimize the fretting wear of con-rod bushing.

According to the contact mechanics theory, the interference amount and friction coefficient of the contact surface were taken as the test factors, and the maximum contact pressure and friction stress under the maximum combustion pressure condition were taken as the objective functions. The influence of the test factors on the objective function was analyzed, and the most reasonable interference amount and friction coefficient were found, so as to slow down the fretting wear of the con-rod bushing.

In the present study, the three-dimensional model of con-rod assembly was established by Creo2.0. The contact analysis of con-rod bushing under the condition of maximum combustion pressure was analyzed. The fretting characteristics of the con-rod bushing were analyzed, and the influence of the friction coefficient and interference on the contact condition of the contact surface between the bushing and the con-rod was studied by designing the orthogonal simulation test. The range of test factor interference and friction coefficient are relatively large, which shows that both interference and friction coefficient have a significant impact on the contact pressure between bushing and con-rod contact surface. The range of friction coefficient is larger than the range of interference, and the difference between them is slightly larger, indicating that the friction coefficient has more significant influence on the friction stress of contact surface. The most suitable friction coefficient and interference amount are 0.15 and 0.11 respectively, which will make the fretting wear condition of the bushing the best.

References

[1] Helal, W. M. K., Zhang, W. P., Li, X. B., & Wang, G. X. (2020). A Study on the Fatigue Strength of a Low-Speed Diesel Engine Connecting Rod Made of 42CrMoA. International Journal of Engineering Research in Africa, 49, 139–151. doi:10.4028/www.scientific.net/jera.49.139

[2] Yanxia WANG, Xinliang QI, Kun HU. (2019). The Reliability Analysis for the Piston, Connecting Rod and Crankshaft Assembly of Diesel Engine. Proceedings of The 3 International Conference on Mechanical Engineering and Mechanics, October 21-23, Beijing, China.

[3] Fan, X., Pan, M. H., & Zhang, C. S. (2010). Fatigue Analysis of Diesel Engine Connecting Rod Based on Finite Element Method. Applied Mechanics and Materials, 39, 550–554. https://doi.org/10.4028/www.scientific.net/amm.39.550

[4] Bin Zheng, Yongqi Liu, Ruixiang Liu and Jian Meng (2011). Finite Element Analysis and Structural Improvement of Farm Engine Connecting Rod. Advanced Materials Research, 2413-2416. 10.4028/www.scientific.net/AMR.291-294.2413

[5] Wasim M. K. Helal et al 2021. Analysis of Low-Speed Diesel Engine Connecting Rod Made of AL360. J. Phys.: Conf. Ser. 1939 012023

[6] S. Khare, O. Singh, K. Bapanna, C. Sasun (2012). Spalling investigation of connecting rod. Engineering Failure Analysis, 19:77-86.