Research on Standard and Automatic Judgment of Press-fit Curve of Locomotive Wheel-set Based on AAR Standard

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Abstract. In the production of the Association of American Railroads (AAR) locomotive wheel-set, the press-fit curve is the most important basis for the reliability of wheel-set assembly. In the past, Most of production enterprises mainly use artificial detection methods to determine the quality of assembly. There are cases of miscarriage of justice appear. For this reason, the research on the standard is carried out. And the automatic judgment of press-fit curve is analysed and designed, so as to provide guidance for the locomotive wheel-set production based on AAR standard.

1. Introduction

The wheel-set is core parts of locomotive bogie. Its assembly method is keyless fitting, that is, the wheel-set assembly equipment is used to combine the wheel and axle assembly. [1, 2] In the AAR standard, the wheel-set is assembled by cold-pressing. [3] As the wheel-set is directly contacted with railway, its assembly quality is greatly related to the running safety of locomotives and vehicles. In the process of production, the real-time press-fit curve formed by NC equipment to record the press-fit force and displacement, which is the important criterion to judge whether the quality is qualified. And it also the only standard to evaluate the quality of wheel-set assembly. [4]

In the Association of American Railroads Standards and Recommended Practices Manual - Wheels and Axles, the press-fit curves are specified and the qualified and unqualified curves are enumerated. Many defects description of press-fit curve is provided in great detail. Based on standard, it is beneficial to standardize the production and improve the quality of wheel-set.

In this paper we put forward an automatic mathematical model by analysis about press-fit curve. And then the corresponding computer automatic judgment program is compiled. It can provide reference for the optimization of the production and maintenance standards on wheel-set. It also helps to the design of the automatic judgment program based on other standard. [5, 6]

In the AAR standard, the press-fit curve of X axis is specified as force F, and Y is specified as displacement L. It’s shown in Figure 1. However, in the actual production, wheel-set assembly machine is often setting displacement as the X axis, and the force is Y axis. This can reflect the tendency of the force to change with the displacement so that the staff can better monitor the press-fit force according to the press-fit curve. [2, 4]
2. AAR standard analyses
When the wheel-set is pressed, the shape of press-fit curve and the final press-fit force are mainly related to the factors such as the amount of interference, the axle taper, the surface, the roughness, the lubrication and the material of axle. Theoretically, the length of AAR standard press-fit curve can refer to the China railway standard, which is indicated as follows: [7]

\[ L = (S + A - K - R) \]  

Among them:
L—The length of press-fit curve.
S—The length of wheel hub bore.
A—The length of the wheel seat extends from the outer end of the wheel hub bore.
K—Taper inlet length of front end of wheel seat.
R—Inner arc radius of wheel hub.

According to standard the length of press-fit curve is divided into three parts in the automatic judgment process. [8] It should be divided into 0 to 25% to 75% to 100% of the displacement. The displacement segment according to the total number of point n divided:

a. The starting section: In the range of (0~25) % of the displacement, the point number:

\[ i = 1~0.25n \]  

b. The middle section: In the range of (25~75) % of the displacement, the point number:

\[ i = 0.25n~0.75n \]  

c. The end section: In the range of (75~100) % of the displacement, the point number:

\[ i = 0.75n~n \]  

2.1. Wire frame judgment
The standard points out that “The displacement, maximum value, minimum value of tonnage should be in accordance with AAR MSRP Section G-II Wheel and Axle Manual. At the beginning of press-fit, the equipment generates the judgment line of the press mounting curve automatically.” When any part of the press-fit curve exceeds the outside of judgment dashed line, it can be judged that the wheel-set is unqualified.

2.2. Force rise sharply
P The standard points out that "The 'entry spike' at the beginning of press-fit must not exceed 30 ton or three times the tonnage after the drop-off whichever is less. For example, if the spike is no greater than 30 ton and the tonnage after the drop-off is no less than 10 ton, the press-fit is acceptable.

The surface of wheel and axle, such as the uneven surface or the wheel and the axle is not moderate which will cause the starting point force to rise sharply. Therefore, there is a strict requirement for the force at the starting point, as follows:
Among them:
\[ m < 0.25n, \text{ } n \text{ is the total number of discrete points of the press-fit curve.} \]

2.3. Determination of the maximum force
The standard indicates: "If the maximum force on press-fit curve is greater than the maximum allow value, the curve is not qualified. This requires all points of the curve to be within the maximum allow value.” This regulation is similar to 2.1:

\[ T_i \leq T_{2\text{max}}, \text{ } i \in \{0,1,2,3 \ldots n\} \]  

2.4. Determination of the final force
The standard reads: “If the final press-fit force is less than the minimum allow value, the curve is judged to be substandard”. This provision is implied in the 2.1-line frame judgment, the requirement:

\[ T_4 > T_{2\text{min}} \]  

2.5. Position judgment
The standard points out: “The press-fit curve is not allowed to fall within the range of 2 tons of the maximum allow force or the minimum allow force. Otherwise it is judged to be unqualified.” This means that the last force must be less than the maximum force of 2 tons, and higher than the minimum force of 2 tons

\[ T_{2\text{min}} + 2 < T_4 < T_{2\text{max}} - 2 \]  

2.6. Force steady rise
The standard points out: The force during the press-fit shall be rising uniformly, and the tonnage shall be established continuously. The 2.6 and 2.7 shall be regarded as coincidence. And the force shall be maintained even rise in the case of no force decline.

2.7. Force down
The standard says: “Starting from the first drop point of the first 25% displacements (no matter how much the force is reduced) until the 75% displacement is calculated. Or if there is no drop in the first 25% displacement, the curve is automatically judged from the first displacement point until the 75% displacement. According to the AAR standard, the force drop before and after the data (including the continuous force decrease of multiple points) exceeds 2 tons and the quality is judged to be unqualified. When the geometry of the press-fit faces is defective, the force at a certain position will decrease briefly. If the lubrication film is not adequately coated, it will cause the force to rise up somewhere and then decrease in tons. These conditions have great influence on the quality of press-fit. Therefore, the curve is required to meet the following conditions:

\[ \text{if } \begin{cases} T_i < T_{i-1}, \quad T_{i+1} < T_i, \quad \ldots, \quad T_{i+k} < T_{i+k-1} \end{cases} \]  

\[ \text{then } T_{i-1} - T_{i-k} < 2 \]  

2.8. Curve completely flat or force drop only
The standard points out: in the first 75% of the press-fit curve, the maximum force cannot appear. That means that the maximum force is at the end section, otherwise the curve is unqualified.

\[ \text{if } T_i = T_2, \text{ then } i > 0.75n \]
2.9. Force fluctuation
The standard states: judging from the start at the 75% point of the press-fit curve. If there is one or more times more than 2 tons of tons (or cumulative drop tons), then determine the end of the press-fit curve appears fluctuation. At the same time, if the end of press-fit force is below the minimum tonnage value, the curve is judged to be unqualified.

\[
\text{if } T_i < T_{i-1}, \quad T_{i+1} < T_i, \quad \ldots, \quad T_{i+k} < T_{i+k-1}, \quad \text{then } T_{i-1} - T_{i-k} < 2, \quad T_i \geq T_2 \min
\]  

(11)

2.10. Curve is not concise
The standard states: if the press force does not meet the minimum press force requirements before the last five acquisition points of the press curve, even if the force for any of the five acquisition points is higher than the minimum tonnage, the curve is still judged to be unqualified.

\[
\text{exist } T_i \geq T_2 \min, \quad \text{and } \quad i < n - 5
\]  

(12)

2.11. Curve reverse crossing
The standard indicates: "when the pressing curve is more than 30 tons of the pressing force, if there is a press fit force, and then return to the limit of 30 tons (including 1 tons of down tons), the curve is judged to be unqualified". It is pointed out in the standard: "when the pressing curve appears first to exceed 30 tons of pressing force and then goes back to the limit of 30 tons (including 1 tons of force down), the curve is judged to be unqualified." This regulation can prevent the interference of the locomotive due to the interference fit is not firm.

\[
\text{if } T_i \geq 30, \quad \text{then } T_{i+k} \geq 30
\]  

(13)

\[
\text{if } T_i \geq T_2 \min, \quad \text{then } T_{i+k} \geq T_2 \min \quad (k=1,2,3\ldots)
\]  

(14)

3. Automatic Judgments Mathematical Model
The basis of establishing the mathematical model of automatic judgment is based on the press-fit curve and the rules in the standard. In the AAR standard, it is necessary to establish the judgment line frame of the standard curve, and set the boundary condition according to the given parameter or the parameter of the calculation formula. In the AAR standard, the numerical value of press-fit force is expressed as T units, and the press-fit curve records are often used KN units, so the corresponding parameters should be adjusted according to the actual situation. As for the parameters in the standard, they are expressed in figures. And the graphics of coarse images can be expressed in the mathematical form and quantified, and then compiled into an automatic judgment program. According to the standards, we design the following model in Fig.2.

![Figure 2. Curve judgment frame](image_url)

Among them:
- T1max - The maximum allow force at the starting point of curve
- T1 - The actual force at the starting point of the force curve
- T2max - The maximum allow force
- T2min - The minimum allow force
- T2 - The maximum force in a curve
- T3 - The down force at the end of the curve (T2-T4)
4. Test and analysis of results

The computer program is compiled according to the automatic judgment model. It is possible to realize the automatic judgment of a curve theoretically. But its reliability needs to be verified by tests. The control system of NC wheel-set assembly machine was designed and developed in the C++ Builder platform. Through the above research and analysis, we are write programs on the basis of the mathematical model. Through the test and historical production data import program to judge. We can verify the accuracy that model identify defects and fit the standard. [9] The automatic judgment process is showed in Fig.3.

![Figure 3. The process of automatic judgment](image)

In the production of wheel-set assembly plant, the majority of qualified curves are shown in Fig.4. When there is a force-drop on the right wheel in Fig.5, the defect cannot be accurately identified only by the human eye. The last force exceeds the T2max in Fig.6. The program has a good judgment result. It can be seen that the accuracy is not high by manual judgment. The algorithm is more effective to solve this problem.

![Figure 4. Qualified curve](image)

![Figure 5. Unqualified curve 1](image)

![Figure 6. Unqualified curve 2](image)
5. Conclusions
In this paper, we study the technical requirements of wheel-set assembly in AAR standard carefully. We have studied the judgment algorithm, and construct the mathematical model of automatic judgment. In fact, qualities testing artificially and automatically are required to be carried at the same time. As the curve that is very difficult for workers to judge, the automatic judgment program can make very good effect. Statistical data show that the accuracy of the automatic judgment program is approximately 100%. The test results verify the effectiveness of the research. The model greatly avoids the mistakes of previous manual judgment and improves reliability of wheel-set. It has important application value for ensuring safety of railway vehicles.

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