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Dimensional Analysis of Coupler Castings

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Summary

As part of an industry effort to improve the performance of coupling components, the Transportation Technology Center, Inc. (TTCI) initiated a research effort to determine component tolerances and the influence of these tolerances on component stress and performance. Using the optimum dimensional tolerances, TTCI will develop a digital master gage as a tool to improve the overall tolerances of E-type coupling system components.

Knuckle and coupler dimensional variations affect component fit, stress, and interchangeability of the parts. Tolerance variations can significantly alter the load path between a knuckle and coupler, and therefore increase stress in critical areas of the parts. A tolerance investigation of over 20 couplers showed that measurements of critical features can vary significantly. Depending on the feature measured, the following variations were observed:

- Total measurement variation of all features ranged between 0.0915 inch and 0.4095 inch.
- Standard deviation of all features ranged from 0.0236 to 0.1015.

In this analysis, TTCI used couplers from three manufacturers to determine if significant differences were present between manufacturers. Comparison of the data from each manufacturer did not show significant separation in performance based on the features measured. Each of the manufacturers had measurements that were least and most deviated from the mean. The analysis indicated that no manufacturer consistently outperformed the other, but did indicate the capability to produce components to tighter tolerances to keep variation at a minimum for some features.

The Union Pacific Railroad provided all of the E-type coupler samples used in the analysis. The coupler samples were new, and once they arrived at the Transportation Technology Center, Pueblo, Colorado, for the analysis, a laser scanning system was used to map their entire surface. These scans were then compared with each other in order to find the differences between dimensions of critical features.

The coupler features that were used for measurements include the top and bottom pivot pin hole, top and bottom pulling lug, inside coupler head, key hole, butt end, and shank. Critical measurements include pivot pin hole alignment, top and bottom pivot pin hole diameter, center of top pivot pin hole to back of top pulling lug, center of top pivot pin hole to back of bottom pulling lug, pivot lug height, inside coupler head width, key hole height, key hole length, key hole to butt end distance, and shank height.

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INTRODUCTION

As part of an industry effort to improve the performance of coupling components, TTCI initiated a research effort to determine component tolerances and the influence of these tolerances on component stress and performance. The research summarized here is part of the Association of American Railroads' (AAR) Strategic Research Initiatives Program (SRI), High Performance Coupling Systems and Castings.

COUPLER ANALYSIS OVERVIEW

An analysis was completed to determine the current tolerances for E-type coupling systems. The analysis was completed in three steps: (1) Build a library of representative samples, (2) Develop 3-dimensional models of the samples using reverse engineering laser scanning techniques, and (3) Create dimensional distributions for measurements that are critical to the performance of the part.

Twenty-two new E-type coupler samples from Union Pacific were selected for the analysis, which included couplers from the three largest manufacturers of coupling system components.

Once the samples were received, each coupler body went through the laser scanning process. During the preliminary laser scanning process, TTCI discovered that all of the critical areas could not be reached with the coupler body intact, so all of the samples were cross-sectioned to enable scanning of the back face of the pulling lugs. Figure 1 shows an example of one of the cross-sectioned coupler bodies.

Figure 1. Example of Coupler Cross-Sectioning

After the couplers were cross-sectioned, scans of the areas of interest on the inside of the coupler body were completed and combined with the outside body scans to generate a point-cloud model of the whole coupler.

The last step in the process was to complete a dimensional analysis of the castings. The most critical aspect of this step was to determine the proper dimensions to compare. Dimensions were selected based on a combination of results from finite element modeling completed under the SRI program in 2010, locations of wear measurements in the AAR's 2011 Field Manual, input from members of the Coupling Systems and Truck Castings Committee, research into lug contact misalignment, and a coupling systems interchange.[1,2,3,4]

TTCI engineers compared selected dimensions between manufacturers and also to the individual manufacturer's components. During this process, the analysis software package PolyWorks® was used to align all of the solid models with a single reference to ensure accuracy of the comparison. A total of 11 measurements were selected as outputs from the software.

The following list shows the features of the coupler body that were measured and compared in the analysis:

- Top and bottom pivot pin hole
- Top and bottom pulling lugs
- Inside coupler head
- Key hole
- Butt end
- Shank

The critical measurements that were output for these features include:

- Pivot pin hole alignment
- Top and bottom pivot pin hole diameter
- Center of top pivot pin hole to back of top lug
- Center of top pivot pin hole to back of bottom lug
- Pivot lug height
- Inside coupler head width
- Key hole height
- Key hole length
- Distance between key hole and butt end
- Shank height

Illustrations for some of the locations and dimensions are shown throughout the remainder of this digest.

PIVOT PIN HOLE ALIGNMENT

Based on the results of finite element work completed in 2010, one of the most critical alignment areas is between the upper and lower pivot pin hole of the coupler body.[1] The results of the finite element analysis (FEA) showed that misalignments between the pivot pin holes significantly alter the load path between the knuckle and coupler. The change in load path results in significantly higher stresses in both the pin support of the coupler body and the pin.

Figure 2 shows the concentric offset measurement between the centers of the pivot pin holes. Once measurements from each of the couplers were collected, data from all manufacturers was compared to determine the maximum and minimum concentric offset.

Figure 3 is a plot of the concentric offset for all of the couplers that were measured for this analysis.

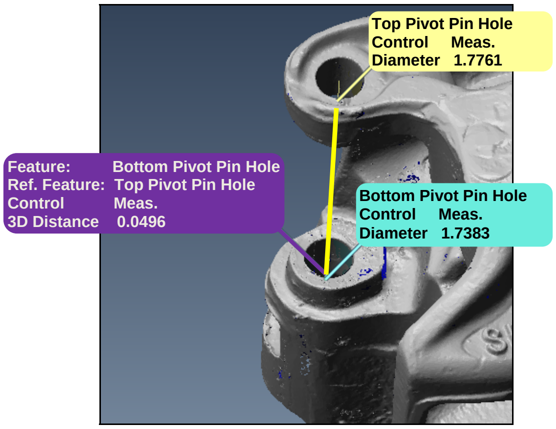

Figure 2. Concentric Offset Measurement between Pivot Pin Holes

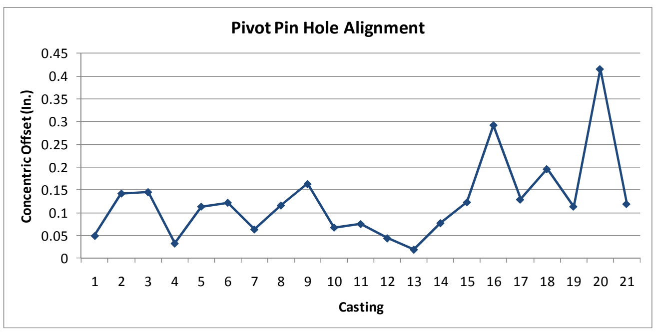

Figure 3. Pivot Pin Hole Alignment

Figure 3 shows that the maximum concentric offset measured for one coupler was 0.4161 inch, whereas the minimum offset was 0.0194 inch. The standard deviation of all of the measurements is 0.0906 inch. The average misalignment is 0.1048 inch between the upper and lower pivot pin hole.

The results of the pin hole alignment dimensional analysis, in combination with previous finite element work, indicate that as the misalignment between the upper and lower pin hole is decreased, the load distribution between the upper and lower pulling lugs is improved and stresses are reduced in the pin and pin support of the coupler body. Additional modeling efforts will focus on the stress distributions based on the tolerances observed during this analysis.

PULLING LUG PLACEMENT

The distance between the center of the top pivot pin hole and the top and bottom lugs is critical because it determines the contact conditions and load path between the knuckle and the coupler, as well as heavily impacting the overall fitment of the two components. Figure 4 shows an example of how the measurements were taken between the center of the top pivot pin hole and the top (in green) and bottom (in red) lugs.

Figure 5 shows the distance between the top pivot pin hole and the top (in green) and bottom (in red) lugs for each of the couplers.

The results in Figure 5 show that more variation is observed in the bottom pulling lug than in the top pulling lug. Table 1 summarizes the maximum and minimum distances between the top pivot pin hole and the top pulling lug, and also the standard deviation for each measurement.

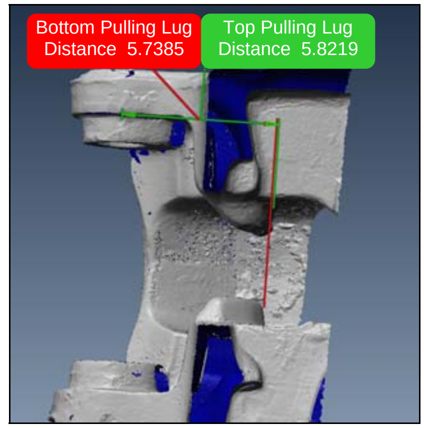

Figure 4. Measurement between Center of Top Pivot Pin Hole and the Top and Bottom Lugs

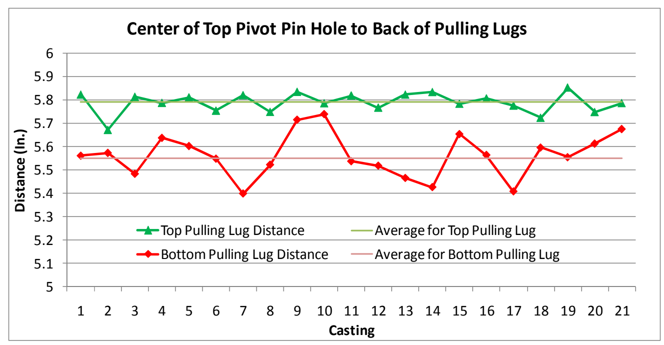

Figure 5. Center of Top Pivot Pin Hole to Back of Pulling Lugs

Table 1. Measurement Summary between Pivot Pin Hole and Lugs

Measurement	Average	Maximum	Minimum	Standard Deviation
Center of Top Pivot Pin Hole to Back of Bottom Pulling Lug	5.5493	5.7385	5.3976	0.0939
Center of Top Pivot Pin Hole to Back of Top Pulling Lug	5.7908	5.8520	5.6707	0.0430

Finite element modeling to determine how the lug placement influences the stress state of the parts has not been completed, but is part of the ongoing research project.

OTHER MEASUREMENT LOCATIONS

Measurements were also taken in several other locations of the coupler that contribute to the overall fit and performance of the part. Table 2 summarizes the maximum, minimum, and standard deviations for each of the locations studied during this research. All of the measurements and observations made from these measurements will be used to determine the influence of the variation in each measurement on the performance of the part.

In addition to Table 2, Figure 6 shows the total measurement variation by feature.

Table 2. Other Measurement Summary

Measurement	Average	Maximum	Minimum	Standard Deviation
Bottom Pivot Pin Hole Diameter	1.7875	1.8997	1.6987	0.0449
Top Pivot Pin Hole Diameter	1.7870	1.8504	1.7250	0.0303
Pivot Lug Height	8.2003	8.2554	8.1311	0.0366
Inside Coupler Head Width	9.6573	9.8119	9.5282	0.0830
Key Hole Length	7.1705	7.3427	6.9331	0.1015
Key Hole Height	1.7188	1.8622	1.6574	0.0475
Key Hole to Butt End Distance	4.0398	4.0810	3.9895	0.0236
Shank Height	6.2104	6.3915	5.9987	0.0920

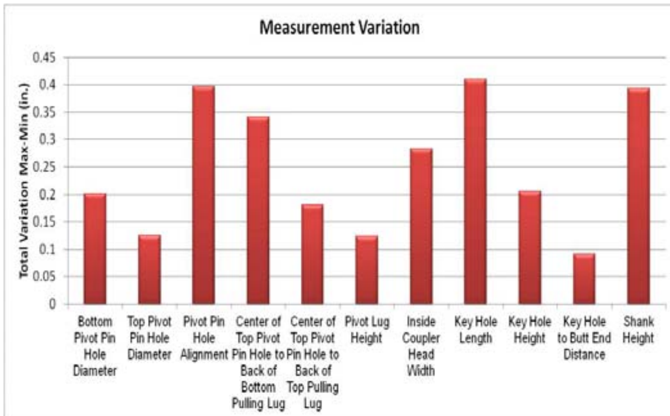

Figure 6. Total Measurement Variation for All Features

The plot shows that variation is the highest in the key hole length and lowest in the key hole to butt end distance. In the next phase of development, the measurement variation shown in this analysis will either be used as inputs into finite element models to determine component stress as measurements vary or to determine the influence of the fitment of the part in the entire coupling system.

Couplers from each manufacturer were also compared to determine the measurement variability between components. Figure 7 shows that no one manufacturer consistently produces higher tolerance parts.

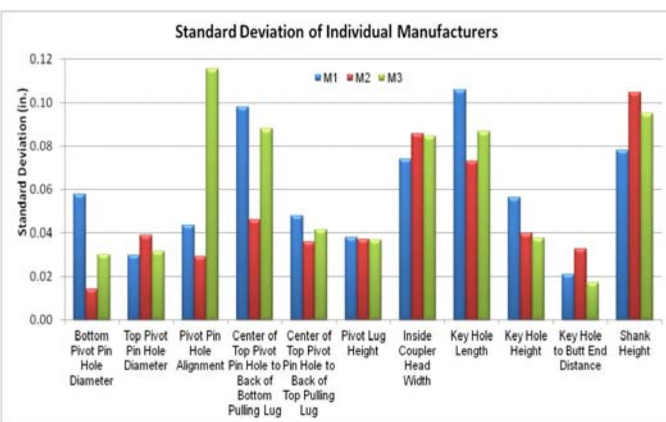

Figure 7. Individual Manufacturer Comparison

CONCLUSION

The features that were measured determine the way the coupler will interact with the knuckle and the draft system of the car. Variations between these features can alter the load path seen by the coupling system. Measurements vary between 0.0915 inch and 0.4095 inch depending on the feature measured. Each manufacturer had coupler measurements that were least deviated from the mean and most deviated from the mean. The standard deviation measurements showed that each manufacturer is capable of keeping the variations at the minimum in some of the locations. The measurements from this analysis will be used to help determine the allowable tolerances for each of the features found in the coupler castings.

FUTURE WORK

As previously mentioned, the next phase in the development is to begin to perform an FEA using the variations measured in this analysis as inputs. A representative solid model will be created for the maximum, minimum, and average measurements for each of the features studied in this analysis. An FEA will then be performed on each of the coupler models and the results will be compared to determine the influence of each modification on the stresses found in the coupling system. The results of the comparison will then be used to develop a set of recommended tolerances for each of the coupler features.

Using the recommended tolerances, TTCI will develop a digital master gage that will be available as a tool to improve the overall tolerances of E-type coupling system components. The digital master gage will be in the form of a solid model of a coupler with the features of interest modified to the optimal locations. This digital master gage will have the capability for each of the manufacturers to compare their own couplers to the digital master gage. This comparison can be performed in foundries and repair/reconditioning facilities. The comparison can be performed by laser scanning a coupler and comparing the scan to the digital master gage. The digital master gage has the potential to improve the performance of the coupling system by increase the dimensional consistency of each casting.

After work is completed on the E-type castings, similar research will be performed for the F-type coupling system components.

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