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Influence of Lug Contact Misalignment on Knuckle and Coupler Stress

Daniel Carter and Kari Gonzales

Summary

Transportation Technology Center, Inc. performed a test to relate stress/strain at critical areas of a knuckle with draft coupler force by recording stress data from an instrumented knuckle and coupler to determine the influence of knuckle and coupler design tolerances and fitment on component stress. This testing will be used to define recommended limits for future standards.

Two of the five knuckles tested experienced brittle fracture during calibration and testing. Both of the fractures were 100-percent brittle, with a small inclusion located on the fracture surface of one knuckle. Data from the strain gages compared to Association of American Railroads' standards showed that in many cases the stress levels exceeded the ultimate strength of the material. These stresses contribute significantly to reductions in component life. In general, results from the tests proved that misalignments between the pulling faces of the knuckle and coupler can result in 40 percent higher maximum principal stresses in critical areas. Tests show that the design and finishing tolerances of the parts at the contact areas are critical to the working stresses in the components.

Additional tests were performed using an instrumented pin to determine the stress conditions in the pin as a result of misalignments at the lug interfaces. Data indicates that under various lug contact conditions, the pin experiences significant loading and results in high stresses in both the upper and lower portions of the pin. This suggests that small misalignments between the knuckle and coupler contact surfaces can have a significant influence on pin stress and may reduce the life of the pin.

Testing was completed using the Simuloader load frame, as shown below, located in the Rail Dynamics Laboratory at the Transportation Technology Center.

Please contact **Dan Carter (719) 584-0577** with questions or concerns regarding this *Technology Digest.* E-mail: Daniel_carter@ttci.aar.com.

INTRODUCTION

Railroads are experiencing increased service failures of couplers, knuckles, and drawgear components, with knuckles accounting for approximately 80-percent of the failures experienced in cast components each year, as seen by the car repair billing database.

Between 2008 and 2009, Transportation Technology Center, Inc. (TTCI) performed several tests to relate stress at critical areas of a knuckle under various lug contact conditions by recording strain data from an instrumented knuckle and coupler. The stress at critical areas of the knuckle will also be compared with over the road test data and results from a Finite Element Analysis (FEA) model to be completed in 2009. The results of testing will be used in fatigue life studies planned for 2010 and to compare to over the road test data to help better understand the current knuckle/coupler operating environment.

TEST DESCRIPTION

Testing was conducted on site using the Simuloader fixture in the Rail Dynamics Laboratory. One test fixture calibration knuckle and four instrumented knuckles (2 E-type and 2 F-type) were loaded in draft a minimum of three times to ensure the repeatability of recorded strain levels. All of the knuckle designs used for testing are currently fully approved by the AAR's Coupling Systems and Truck Castings Committee (CSTCC) in accordance with AAR M-201[1] and M-211[2] specifications for material requirements. All knuckles were inspected for surface defects using a magnetic particle inspection prior to applying strain gages and conducting tests.

Figure 1 shows the six strain gage placement locations used for each knuckle. A single gage was placed on the upper and lower pulling face of the knuckle and the upper and lower pulling lugs. A rosette strain gage was placed on the top surface of the knuckle near the coupler pin hole and another was placed near the transition to the lugs next to the pulling face (transition area).

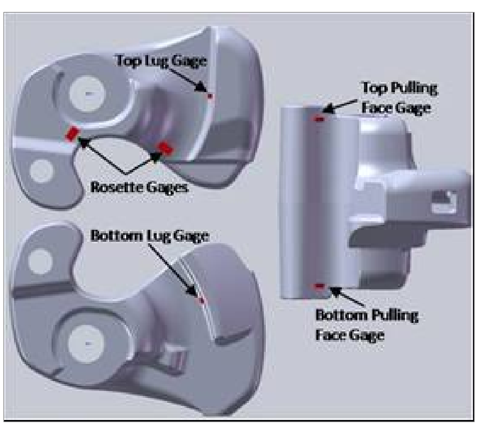

Figure 1. Knuckle Strain Gage Locations

In addition to the strain gages on the knuckle, several strain gages were located on the coupler to provide information on the load transfer between the load cell, coupler, and knuckle. Strain gages were also placed on the upper and lower lug of the coupler.

Data was recorded for both the loading and unloading sequences for each of the pull tests. Loads were applied from 10,000 pounds to 400,000 pounds at a rate of 10,000 pounds per second. The maximum load was held for a minimum of 30 seconds and then gradually released before repeating the load application. After a minimum of three load cycles was completed in the as-is contact alignment state, steel shims were placed between the coupler and knuckle lugs in various positions to alter the alignment and fitment conditions between the knuckle and coupler. The combined thickness of the two shims placed at the lug interface was 0.035 inch. The following list summarizes the test matrix used for each knuckle/coupler combination:

1. Even lug engagement between the top and bottom lugs of the coupler and knuckle (as-is state)
2. Top lug engagement only (shims placed at the top lug interface)
3. Bottom lug engagement only (shims placed at bottom lug interface)

Several shim variations were used for Nos. 2 and 3 in the test matrix list. Data was collected with a maximum of two shims placed between the pulling lugs.

A second set of tests was performed using an instrumented pin to determine the stress levels experienced at the top and bottom of the pin under various knuckle/coupler interface conditions. The pin was instrumented using a layout similar to that described by Tanzer (R-745).[3] Figure 2 displays the initial pin orientation (left) and the strain gages (right) used for the instrumented pin testing sequence.

A test to determine the pin angle, which results in the maximum stress on the pin, was completed before any shims were added to the lug interface. To define this angle, a series of draft loads were applied from 0 to 100,000 pounds in the initial position shown in Figure 2. After the strains were recorded in the initial position, the pin was rotated through 180 degrees in 5-degree intervals to determine the angle of maximum stress. Once this angle was determined, the pin was placed in this position for the remainder of the lug misalignment testing. Before the test matrix listed above was completed, a stepped pull was performed at loads of 100,000, 200,000, 300,000, and 400,000 pounds to ensure that no residual stress was in the pin.

Figure 2. Instrumented Pin

DATA REDUCTION

Data was collected at 256 samples per second for all tests. The unfiltered strain data was then converted to stress data using TTCI's MultiVu data analysis software. The maximum principal stress for each of the channels was calculated and recorded for each run.

STATIC TEST RESULTS

Two of the five knuckles tested experienced brittle fracture during testing. During calibration of the load frame, one F-type knuckle fractured at the pin hole. The estimated maximum load applied at the time of fracture was 450,000 pounds. The fracture face did not show any indications of metallurgical flaws. The break was a 100-percent brittle fracture.

The second fracture occurred during testing of the instrumented F-type knuckle. The break occurred at 400,000 pounds and once again was observed to be a 100-percent brittle fracture. One small inclusion was present, but no fatigue associated with the inclusion was observed. Figure 3 shows the broken knuckle fracture surface.

Figure 3. Knuckle Fracture Surface

Table 1 shows that both fractures occurred well below the specified limits for Grade E material listed in the AAR M-211 standard.[2]

Table 1. AAR Static Tension Test Requirements

Casting	Maximum Permanent Set (inch)		Minimum Ultimate (pounds)
	@ 400,000 pounds	@ 700,000 pounds	
Knuckle	0.03	-	650,000
Coupler	-	0.03	900,000

Data from the strain gages placed on the pulling lugs was inconsistent due to contact in the area. The strain gages and wiring were replaced on some knuckles due to loading damage. Data from the rosette strain gages installed near the pin hole and transition area were more consistent because no loading is directly applied to those areas.

Figure 4 is a plot of the maximum stress experienced at each strain gage under the as-is and shimmed conditions for the F-type knuckle and coupler assembly that did not fracture. The x-axis shows the strain gage location and the y-axis shows the maximum stress value, in units of 1,000 pounds per square inch or ksi, recorded at that location. The purple diamonds represent the no-shim condition. The maroon squares and green triangles represent the bottom and top shim conditions, respectively.

Stress levels for the F-type knuckle ranged from 60 ksi at the top lug to almost 200 ksi at the bottom lug when no shims were present. When shims were placed between the top lugs of the knuckle and coupler, stresses ranged from 60 ksi at the top lug to 170 ksi at the bottom lug of the coupler. Finally, when shims were placed at the bottom lug interface, stresses ranged from 48 ksi at the top lug to 230 ksi at the bottom lug of the coupler. The coupler top lug data could not be used for this analysis because of damage to the strain gage during loading. The data in Figure 4 indicates that when small misalignments (0.035 inch) occur between the contact surfaces of the coupler and knuckle, critically high stresses result in several areas of the components. Similar results were observed for the tests conducted using the E-type knuckle/coupler assemblies.

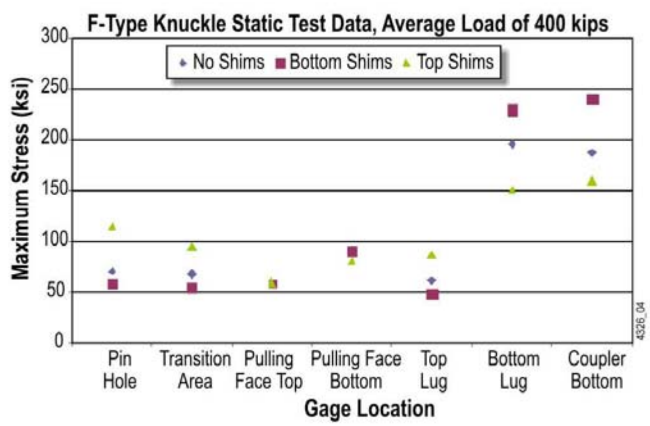

Figure 4. Stress Data for F-type Knuckle

Comparing stress levels to the AAR M-211[2] specified yield and ultimate strength of the materials (100 ksi yield and 120 ksi ultimate) shows that in many cases stress levels are exceeding the ultimate strength of the material. The stresses that are occurring may be localized due to the loading conditions, but they are still likely to significantly contribute to reductions in component life. FEA and fatigue life studies are in progress to better understand the nature of the stress fields in the knuckle and coupler under various contact interface conditions.

INSTRUMENTED PIN TEST RESULTS

Figure 5 displays the stress data for the upper and lower strain gages mounted on the pin during static testing. The stress in the upper portion of the pin is shown in blue and the stress in the bottom of the pin is shown in red. The data in Figure 7 shows that with a 100,000-pound applied load, at an angle of 50 degrees from the starting point results in the highest stresses in the upper and lower portion of the pin. The maximum observed stress in the pin at 100,000 pounds was 55 ksi for the upper strain gage and 39 ksi for the lower strain gage.

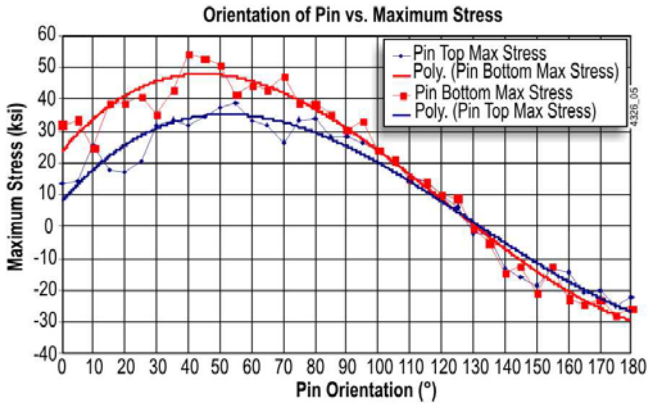

Figure 5. Pin Orientation Stresses

Figure 6 shows the results of the stepped load testing. Comparing the top (blue) and bottom (red) pin stresses shows a 1.26 ksi difference at 100,000 pounds of applied load and a 62.16 ksi difference at 400,000 pounds of applied load. The data shown in Figure 6 indicates that as the draft force was increased the top of the pin received more of the load than the bottom of the pin. This trend may be component specific and additional testing must be completed before concrete conclusions can be drawn.

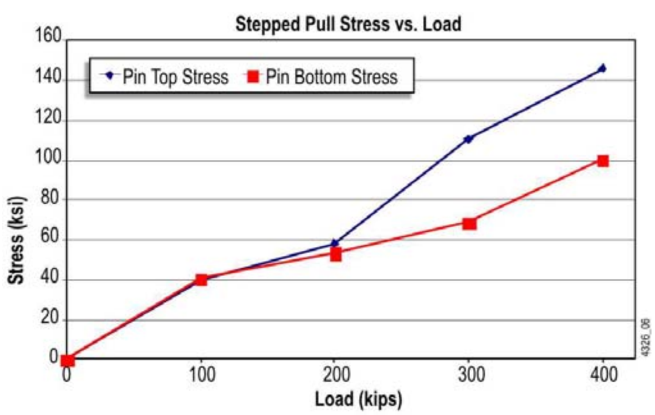

Figure 6. Stepped Pull Stresses

The last set of testing with the instrumented pin was completed using the matrix used in the knuckle and coupler testing to determine the influence of lug contact misalignments on pin stress. At the conclusion of testing, the instrumented pin was removed and a bend was observed. Because it is unknown when the bend in the pin occurred, more testing will be required to validate the stress results observed.

Figure 7 shows the stress results from the shim testing with the instrumented pin.

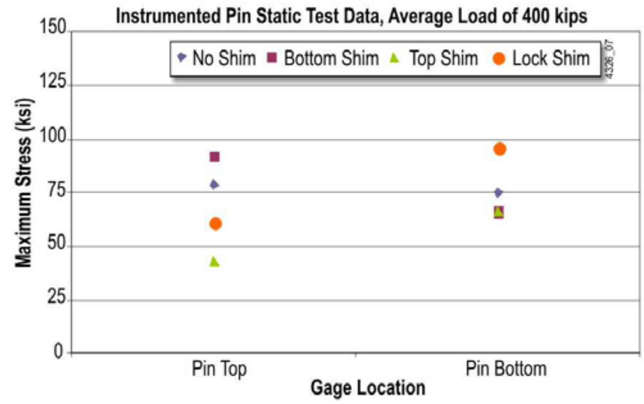

Figure 7. Pin Stress Data

Pin stress levels ranged from 75 ksi to 79 ksi at the bottom and top of the pin, respectively, with no shims at the lug interface. After shims were placed at either the lug or lock interfaces, pin stress ranges from a minimum of 43 ksi at the top of the pin when shims were located at the top lugs to a maximum of 92 ksi at the top of the pin when shims were placed at the bottom lug interface. The data collected during this testing suggests that small misalignments between the knuckle and coupler contact surfaces can have a significant influence on pin stress and may reduce the life of the pin.

CONCLUSION

The testing examined the stress in the knuckle/coupler assembly during draft loading resulting from various lug contact conditions. Placing shims between the top or bottom coupler and knuckle lugs caused the stress to increase at these locations as well as on the pin hole and pulling face of the knuckle. Small changes in fitment between the top and bottom lugs can cause the adverse changes in the stress levels observed in the pin and the pulling face of the knuckle because of the modification of the load distribution between the upper and lower lugs. The observed increases in component stresses indicate that the tolerances for both knuckles and couplers are extremely important when considering working stresses of the components and ultimately, component life.

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