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RESEARCH RESULTS
FRA OFFICE OF RESEARCH, DEVELOPMENT & TECHNOLOGY

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EXPERIMENTAL RESULTS OF RAWCAD STATIC TEST

SUMMARY

From September 7, 2018, to December 16, 2019, the Federal Railroad Administration supported the performance of semi static tests on two cracked axles as part of the Resonant Acoustic Wayside Automated Cracked Axle Detection (RAWCAD) project. The performance of detection algorithms for distinguishing frequency shift in cracked axles was evaluated at the Transportation Technology Center (TTC) in Pueblo, CO. Two cracked axles were tested, one on each of the two railcars. The remaining axles on both cars were unblemished. Originally, locations of the cracked axles were unknown to the analyst, making this initial evaluation a blind test of the detection algorithm. This test procedure called for impacting each axle with a hammer and measuring the response with an accelerometer attached to the axle. This impact/measure sequence was repeated as the railcar was indexed forward an incremental distance. Since the crack breathing phenomenon causes a crack to open and close once per revolution, the measured frequency response for the cracked axle should vary as the railcar is moved through one complete wheel revolution. Alternatively, there should be no shift in the frequency response for uncracked axles.

BACKGROUND

The catalyst for the RAWCAD project was the work completed during the original research for hollow axles as part of the wheelset integrated design and effective maintenance (WIDEM) program reported by Verhelst [1]. He reported a frequency downshift in the axle resonances on the order of 0.2 percent after the axles were fatigue tested and cracks were visible. Verhelst did not provide information regarding the size of the cracks corresponding to this level of frequency downshift. Further research revealed that Rudlin investigated the performance of various NDT methods of these same axles as part of the WIDEM program [2]. Crack lengths and the resulting frequency shifts reported from the fatigue testing at Lucchini [1] [2] show crack lengths range from 80 mm (3.14 in.) to 20 mm (0.78 in.). Using a peak picking algorithm described in Verhelst [1], the frequency downshifts (corresponding to fatigue test cracks) range from 0.08 to 0.11 percent (note that this is different than the 0.2 percent downshift incorrectly stated by Verhelst for the same data set). Multiple cracks are reported for each axle. In Figure 1 the main crack is on the order of 3 cm, but there also are a number of smaller cracks.

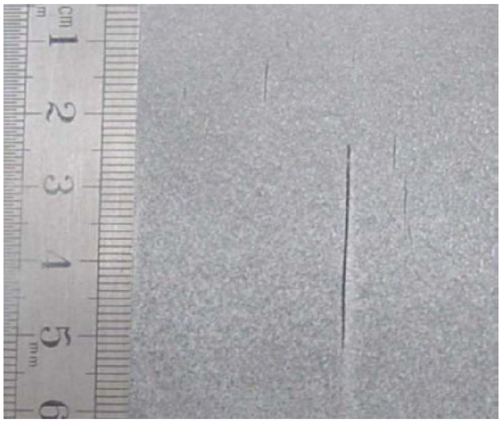

Figure 1. Typical crack group resulting from WIDEM fatigue testing at Lucchini

Figure 2 shows the crack for one of the two solid axles from TTCI (Axle 1822). This axle was removed from the heavy axle load train operated at the TTC's Facility for Accelerated Service

Testing (FAST). The crack is similar in size to that shown in Figure 1 for the Lucchini axle. The crack is made visible by the use of a dye applied to the axle at the crack location.

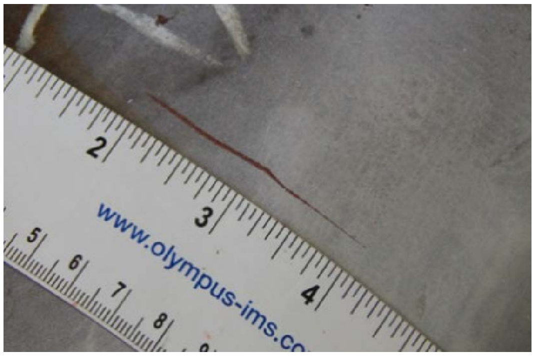

Figure 2. Transportation Technology Center, Inc. (TTCI) cracked axle (Axle 1822)

OBJECTIVES

This testing was performed to validate the resonant acoustic automated cracked axle detection algorithm. The algorithm is based on the hypothesis that cracked axles will result in a once-per-revolution frequency shift as the axle crack breathes throughout a full revolution.

METHODS

Accelerometers were placed on the test axles. Impact was applied by hand using a hammer. Access to the axle was provided by parking the car over a service pit.

ALGORITHM

Algorithms for detecting crack breathing were developed by Vibroacoustic Concepts (VaC). Figure 3a–d shows the steps in these algorithms and typical results obtained. Figure 3c shows that the peak picking algorithm yields many frequency peaks corresponding to each response spectrum. Furthermore, the same frequency peaks are not present for each impact response.

To reduce the amount of data and increase the data quality, only the spectral peaks which are present for each of the multiple impacts are selected. The algorithm then determines a frequency band and selects only the frequency peaks that occur for each position. Figure 3d shows a typical result for this step. Finally, by plotting the actual frequencies for each axle rotation, it is then possible to determine the amount of frequency shift.

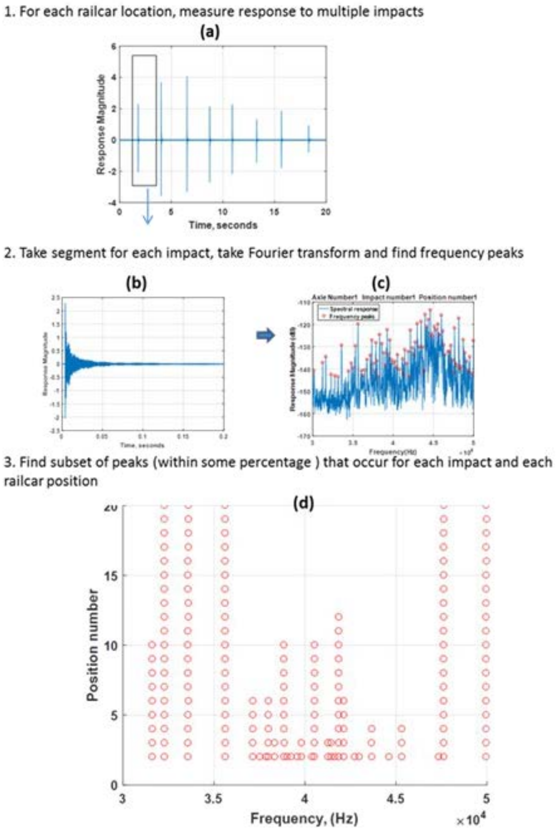

Figure 3. Algorithm for determining axle frequency shift vs axle position

RESULTS

The results obtained using the crack shift algorithm are shown in Figure 4 through Figure 11. Each of these graphs represents the frequency response variation for three selected frequencies over a complete wheel revolution. Theoretically, the results for the cracked axle would show a sinusoidal frequency shift. In fact, all the axles on UP 33394 show some amount of frequency shift, but none of them show a consistent once per revolution frequency shift as expected. Instead, all the graphs show a frequency variation on the order of 10 to 20 Hz.

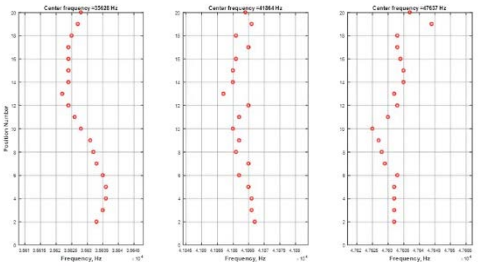

Figure 4. UP 33394 Axle 1

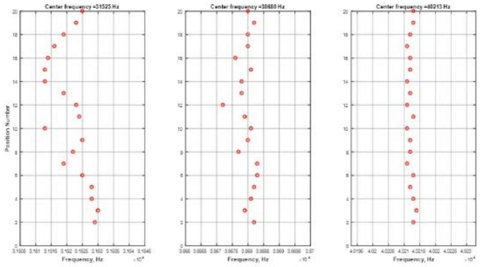

Figure 5. UP 33394 Axle 2

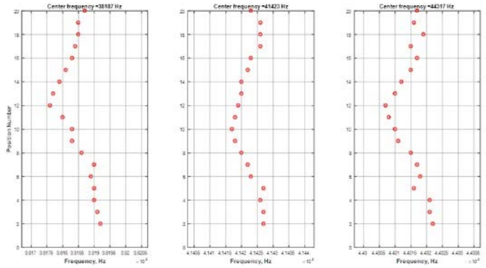

Figure 6. UP 33394 Axle 3 (cracked)

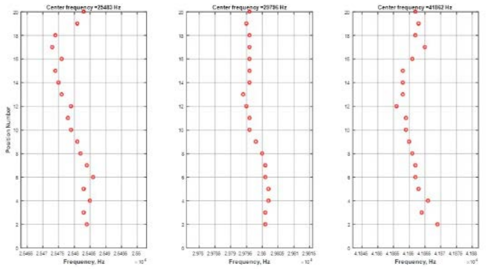

Figure 7. UP 33394 Axle 4

Similarly, the results for car NW 1200042 do not clearly indicate a cracked axle (Figure 8 to Figure 11). Good axles 2, 3, and 4 show little variation, but the cracked axle (Axle 1) does not vary as expected over all of the frequencies.

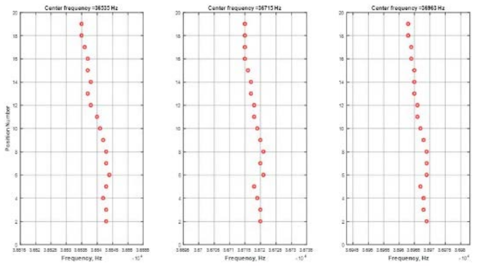

Figure 8. NW120004 Axle 1 (cracked)

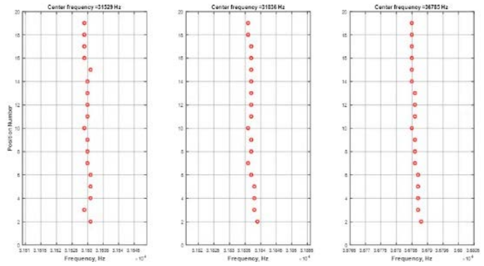

Figure 9. NW120004 Axle 2

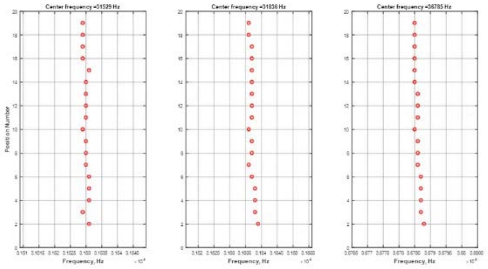

Figure 10. NW120004 Axle 3

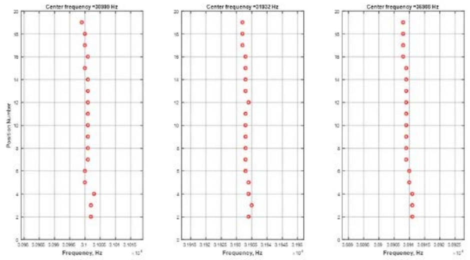

Figure 11. NW120004 Axle 4

CONCLUSIONS

Based on the results presented, it is not possible to reliably distinguish which of the axles is cracked using the proposed algorithm. None of the results show frequency shifts as large as predicted using the simulation. A comparison of

WIDEM and TTCI axle cracks indicates that these two cracks are of similar size. Note, however, that there is only one crack evident in the TTCI axle as compared to multiple cracks that resulted from fatigue testing of the hollow axle at Lucchini (WIDEM axle). It is possible that larger frequency shifts will occur for crack groups or deeper cracks. Another possibility is that the variance is due to differences between hollow and solid axles. In addition, there was larger than expected variation for the uncracked axles. This unexpected variation suggests an as yet unexplained noise source.

FUTURE ACTION

Blind testing did not reveal conclusive results indicating which of the four axles is the cracked axle on either railcar. The following recommendations are suggested:

1. Vibroacoustic Concepts, LLC will further examine the data taken on March 6, 2019, with knowledge of which of the axles is cracked in an attempt to refine the crack detection algorithm.
2. Further static testing has occurred. Axles with larger cracks and cracks in different locations on the axles may be investigated. It may be necessary to further fatigue axles in order to produce samples which can be reliably detected. Consideration will also be given to experimental controls for understanding the variations in readings for some of the uncracked axles.

REFERENCES

1. Verhelst, W. (June 30, 2008). “Development of compensated resonance inspection prototype for Wheelsets” WIDEM Project D6.1.
2. Rudlin, J. (June 30, 2008). “Report on NDT performance (various techniques) for conventional wheelsets” WIDEM Project D6.2.

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