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Slack Action Effects on Undesired Emergency Brake Applications

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Summary

Transportation Technology Center, Inc. (TTCI) studied the effect of slack action on brake pipe pressure (BPP) fluctuations in order to investigate root causes for undesired emergency brake applications (UDEs). Consists with as many as 63 railcars were exposed to both quasi-static and dynamic testing scenarios with in-train coupler forces approaching 400 kips. Each scenario consisted of trials with and without a minimum service brake application to assess the influence of air brake and slack action on BPP fluctuations.

The test runs did not result in a UDE. To allow comparisons with previous laboratory testing of valves prone to UDEs, moving averages of the BPP reduction rates were calculated using window sizes of 10, 25, 50, 75, and 100 milliseconds (msec). When analyzing the data using a moving average window size of at least 50 msec, maximum BPP reduction rates exceeded only the lowest critical reduction rate for a potential UDE when service braking was combined with slack action. The test results demonstrated that slack action alone did not approach the lower limits of a potential UDE until a moving average window of 25 msec or smaller was applied to the data. There is some uncertainty about critical BPP reduction rates for such short time increments.

Data for this study was acquired traveling uphill and downhill on a grade of approximately 0.86 percent at the Transportation Technology Center (TTC). The investigation was undertaken by TTCI as part of the AAR Strategic Research Initiative on Improved Performance of Brake Systems. The investigation of UDE root causes will continue with additional laboratory testing and data analysis to better quantify the minimum period of BPP fluctuation required for UDE response.



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INTRODUCTION

To investigate root causes for undesired emergency brake applications (UDEs), TTCI tested the effect of slack action on brake pipe pressure (BPP) fluctuations using consists with as many as 63 railcars. The test runs did not produce a UDE and, when analyzed with moving average window sizes of at least 50 milliseconds (msec), the BPP reduction rates did not reach levels associated with UDE until service braking was used in combination with slack action.

BACKGROUND

Previous researchers theorized that BPP fluctuations ranging from 35 to 40 psi/sec lasting an estimated 10 msec could cause control valves in a normal operating condition to respond with an emergency brake application. Testing was performed in the late 1980s to validate this theory using three different consist configurations (32, 36, and 41 total railcars). This testing provided evidence that harsh slack action can cause pressure fluctuations of up to 2 psi at rates approaching 30 psi/sec.¹ The results of this testing concluded that slack action can cause BPP fluctuation rates that approach the lower limits of the theorized UDE values. Pressure pulses were found to be caused by the deceleration of vehicles, and these pulses were also able to combine with the pressure waves from service braking applications to increase the BPP reduction rates. Additional testing was recommended to use a larger consist to increase the slack action available, and thus, produce a more accurate representation of longer trains in revenue service.¹

Another study performed by TTCI examined 200 event recorder files from two major railroads that included UDEs on moving trains. It was found that only 36 percent of sampled UDEs were caused by a valve overreacting to a service brake application (typically a minimum service application). The majority of UDEs were found to occur in the absence of service braking, but shortly following potential slack action as determined by throttle and dynamic brake commands.²

In late 2016 and early 2017, service stability testing was performed on air brake equipment removed from 43 railcars suspected of causing multiple UDEs. Individual valves were installed on a single car test rack and were tested with a programmable pressure control device. Each valve was subjected to various BPP decreases over varying time periods to create thresholds for performance. A map was then created from all valves tested to illustrate the stable, inconsistent, and unstable regions over varying time windows.³

TEST DETAILS

TTCI designed a test based upon the previous findings from the work that was performed at TTC in the late 1980s. A consist was created from a mix of empty and loaded railcars donated from the Union Pacific Railroad and CSX Transportation. Two consist configurations were used during the testing. Table 1 shows the various consist setups (E=empty, L=loaded, DG=draft gear, CU=cushioned). Configuration #1 totaled approximately 3,617 feet and 3,757 tons. Configuration #2 totaled approximately 3,883 feet and 4,544 tons.

Table 1. Test Consist Configurations

Position in Consist	Description	Load Status	Draft System	Instrumented Car
1-3	Locomotives	N/A	DG	
4-8	125-ton coal gondolas	L	DG	
9	100-ton covered hopper	L	DG	#1
10-21	100-ton various types	E	DG	
22	100-ton covered hopper	L	DG	#2
23-34	100-ton various types	E	CU	
35	100-ton covered hopper	L	DG	#3
36-47	100-ton various types	E	DG	
48	100-ton covered hopper	L	DG	#4
49-60	100-ton various types	E	CU	
61	100-ton covered hopper	L	DG	#5
62-66	125-ton coal gondolas (Configuration #2 only)	L	DG	

In Configuration 2, five loaded 125-ton gondola cars were added to the rear of the consist to increase the in-train forces and study its effect on the slack action and resulting BPP reduction rates. A combined total of 24 railcars with end-of-car or center-of-car cushioning were arranged into two blocks of 12 railcars each to provide slack action displacement. Five covered hopper cars were dispersed evenly throughout the consist to serve as instrumentation cars. The instrumentation cars each contained a battery powered data acquisition system and the following devices:

- One accelerometer (longitudinal direction)
- Two string potentiometers (coupler displacement)
- Two pressure transducers (BPP, brake cylinder pressure)
- One force measuring coupler (force measured on systems 1,3, and 5 only)
- One global positioning system receiver for speed measurement and data system time synchronization

Each transducer was collected at a sample rate of 1,000 samples per second and was post processed through a 100 Hz lowpass filter. The location for the testing was the Precision Test Track (PTT) at the TTC.

Quasi-static and dynamic testing procedures were used to study the BPP reduction rates under different conditions. Test runs were typically executed first without any service braking, then repeated using a minimum service brake application approximately 1 second after the locomotives began to move in the quasi-static tests or 1 second after the dynamic brakes were applied in the dynamic tests. Tests were first performed traveling southbound on the PTT with a downhill grade of approximately 0.86 percent. The consist was then turned around to repeat the tests using an uphill grade in order to study its effects on the test parameters.

The quasi-static tests were performed in two different scenarios to create maximum buff and draft forces independently of each other. The forward tests began with the consist bunched. The locomotives then accelerated rapidly away from the consist at throttle settings as high as notch 4 until the rear car began to move. Alternatively, the backward tests began with the consist stretched. The locomotives would then accelerate rapidly backward into the consist at throttle settings as high as notch 6 until the rear car began to move.

In the dynamic tests, the locomotives would gradually bring the consist to a desired speed between 10 and 20 mph. Once speed was maintained, the locomotive engineer would set the dynamic brake at a specified level as high as brake 8 to cause a run-in. Later test runs used the independent brake in conjunction with the dynamic brake to increase the run-in buff forces.

RESULTS

The test matrix produced a total of 64 runs: 36 runs focused solely on the effect of slack action and 28 runs consisting of the general test procedure with the addition of a minimum service brake application. No UDEs were triggered during either testing scenario. Test parameters were selected iteratively by increasing the speed or the target settings for throttle or dynamic brake after checking the maximum coupler forces from the previous test conditions. Maximum buff and draft forces of approximately 380 kips and 270 kips, respectively, were obtained.

The BPP time history was differentiated to obtain the corresponding BPP reduction rate (psi/sec). As in previous testing, moving averages of the BPP reduction rates were calculated using window sizes of 10, 25, 50,

75, and 100 msec. Figures 1 and 2 display histograms of the maximum BPP reduction rates per test run for each instrumented car for the 100 msec window with and without a minimum service brake application, respectively. As expected, the results generally show an increase in the BPP reduction rates when a minimum service brake application was used during the test trials.

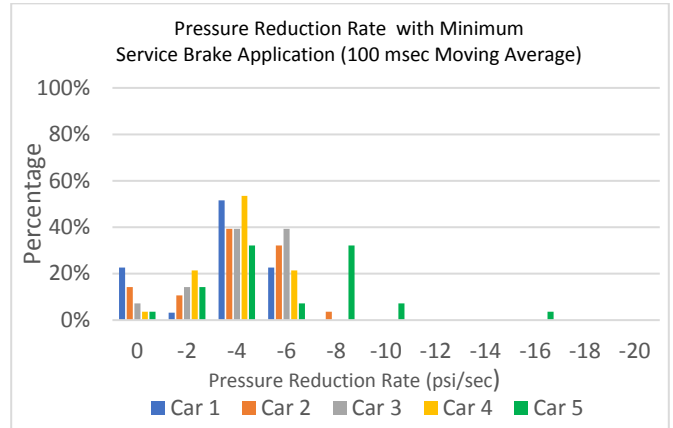


Figure 1. Histogram for BBP Reduction Rate with a Minimum Service Brake Application (100 msec Moving Average Window)

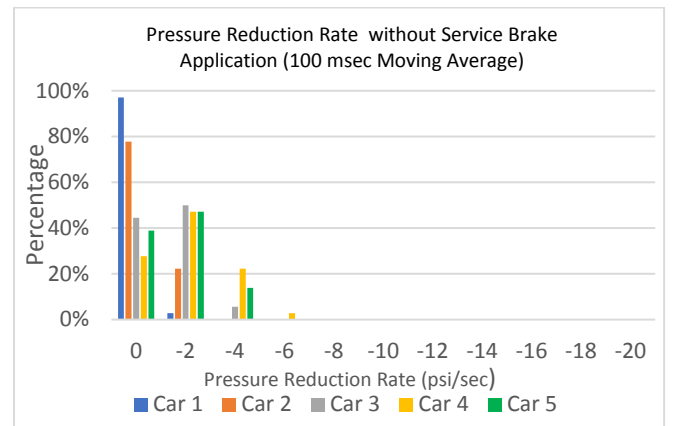


Figure 2. Histogram for BBP Reduction Rate without a Service Brake Application (100 msec Moving Average Window)

Table 2 displays the maximum BPP reduction rates observed for various moving average window sizes. Red highlight is used where the observed value exceeds the lowest critical rate³ as specified in the bottom row, theoretically indicating potential for UDE. It is important to note that the critical UDE rates listed were obtained by finding the highest BPP reduction rate over the specified moving average window size from BPP fluctuations that typically occurred over a longer duration (on the order of several hundred msec). Thus, the critical rates listed for the shorter moving average windows may be lower than the true limit of stability for very short duration fluctuations.

Table 2. Maximum BPP Reduction Rates (psi/sec)

Car	Minimum Service Brake Application	Moving Average Window Size (msec)				
		10	25	50	75	100
1	Yes	26.6	15.1	9.3	8.6	7.5
2	Yes	20.0	12.4	10.7	8.9	8.1
3	Yes	46.1	17.7	8.9	8.1	7.1
4	Yes	36.8	22.0	11.0	8.3	6.7
5	Yes	23.7	21.0	19.7	18.5	17.1
1	No	20.4	11.0	6.1	2.6	2.4
2	No	30.2	9.3	6.0	4.0	3.2
3	No	50.1	28.2	8.7	6.0	5.3
4	No	84.3	24.9	14.9	11.0	6.0
5	No	25.9	11.8	9.6	7.0	5.0
Lowest Critical Reduction Rate for Potential UDE ³		23.2	22.7	18.8	17.1	15.9

When the results are analyzed with moving average window sizes of 50 msec or larger, the maximum BPP reduction rates exceed the lowest critical reduction rate for potential UDE only when service braking is used in conjunction with slack action and only at the rear of the train. In other words, slack action alone was insufficient to generate BPP reduction rates potentially capable of causing a UDE as determined from control valves suspected of having a history of UDEs.³

However, when analyzed with shorter moving average windows of 10 msec and 25 msec, the results show different trends. For example, some of the largest BPP reduction rates occurred without service braking. Also, the maximum BPP reduction rates using these short moving average windows sometimes exceed the lowest critical reduction rate for potential UDE by large amounts (in the most extreme case by more than 360 percent). As stated previously, no UDEs were experienced during the testing scenarios. This may indicate that the critical rates listed in the last row of Table 2 for 10 msec and 25 msec moving average windows are lower than the true critical rates for these time durations.

Instrumented Car 5 positioned at or near the extreme rear of the train typically experienced the largest BPP reduction rates during the trials with a minimum service

brake application. However, Instrumented Car 4 had most of the largest BPP reduction rates during trials without a service brake application.

Correlations were not found between the BPP reduction rate and the maximum coupler force or maximum longitudinal acceleration.

CONCLUSION

TTCI analyzed the effect of slack action on BPP reduction rates in consists as long as 63 railcars. Quasi-static and dynamic tests were used to create large accelerations and in-train forces that exposed brake control valves to pressure pulses in the brake pipe. Despite obtaining coupler forces approaching 400 kips, a UDE was not triggered from the testing scenarios. When analyzing data using a moving average window size of at least 50 msec, maximum BPP reduction rates reached levels of concern for UDE only when service braking was combined with slack action. Slack action alone did not approach levels of concern for a UDE, even when considering the performance of control valves suspected of having a history of UDEs, until moving average windows of 25 msec or smaller were applied to the data. However, there is some uncertainty about the critical BPP fluctuation rates at such short durations. Consists significantly longer than 63 railcars could experience higher BPP reduction rates due to slack action.

FUTURE WORK

TTCI will continue this investigation by quantifying the UDE performance of new and recently reconditioned control valves when exposed to short duration BPP fluctuations. Also, TTCI will analyze new and existing data to better quantify the minimum period of BPP fluctuation required for UDE response.

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