TECHNOLOGY DIGEST

TD-15-046

©DECEMBER 2015

TIMELY TECHNOLOGY TRANSFER

The work described in this document was performed by Transportation Technology Center, Inc.,
a wholly owned subsidiary of the Association of American Railroads.

Relationships of Brake Pipe Leakage, Flow, and Gradient

Joel Kindt, Scott Cummings, Devin Sammon, and Brent Whitsitt

Summary

Transportation Technology Center, Inc. (TTCI) has developed regression equations to predict the air flow rate and gradient of an assembled train based on the yard air test results of individual segments of that train. A train needs to meet minimum requirements of the regulatory Class I brake test prior to departing the initial terminal: brake pipe air flow not greater than 60 cubic feet per minute (cfm) and pressure difference between head and tail end (gradient) not greater than 15 pounds per square inch (psi). Individual train segments are usually tested using a fixed source of pressured air in the yard and leaks are isolated before the train is assembled. However, the results of individual segments do not directly relate to the flow and gradient of an assembled train. Another challenge is that train segments in the yard are frequently tested using the leakage rate method, which does not require air flow meters but is highly dependent on the consist length. This *Technology Digest* presents relationships in which a pressure meter can be used to estimate the flow rate of individual train segments. Further relationships are established to predict how the placement of multiple segments will affect the assembled train.

Data was acquired onsite in the air brake laboratory at the Transportation Technology Center (TTC). The tests followed a predetermined test matrix that includes different charge pressures, consist lengths, leak locations, and leak severities. The data was post-processed and analyzed to establish the necessary relationships. Limited validation testing for the assembled train in the brake lab showed that the predicted flow rate was typically within 5 to 10 cfm and predicted gradient was within 2 to 5 psi of the correct values depending on whether the individual segment air flow rates or leakage rates were used as input.

This investigation is being undertaken by TTCI under the sponsorship of the Association of American Railroads through the Strategic Research Initiative on Brake Systems.

Please contact **Scott Cummings (719) 584-0739** with questions or concerns regarding this *Technology Digest.* E-mail: Scott_Cummings@ttci.aar.com.

INTRODUCTION

TTCI conducted testing in the air brake laboratory at the TTC to establish regression relationships between various brake system parameters. A spreadsheet was produced that allows railroad personnel to enter typical measurements obtained during yard air tests on train segments and produce a predicted air flow and gradient value for an assembled train. This work was performed for the Association of American Railroads' (AAR) Strategic Research Initiative on Brake Systems.

BACKGROUND

The Class I brake test[1] requires that a train meet minimum standards for brake pipe pressure gradient and either leakage rate or air flow rate before departure of the initial terminal where the train is assembled. Gradient is the difference in pressure between the car nearest to the air supply and the car farthest from the air supply when the brakes are released. Leakage rate is measured with a pressure gage after making a 20-psi brake pipe pressure reduction, removing the air supply, and waiting for 45-60 seconds. Air flow is measured with the air flow meter on the locomotive when the brakes are released. Regardless of train length, the Class I brake test allows a maximum of 15 psi gradient and either 5 psi per minute leakage rate or 60 cfm air flow.

As a practical matter, railroads frequently build multiple train segments on different tracks in a yard before assembling a complete train. This allows the brake systems of each segment to be tested separately by mechanical staff using a fixed source of pressurized air so that leaks can be identified and addressed before involving locomotives and transportation staff. Air flow meters are not always available to mechanical staff, so they frequently use pressure gages to determine the gradient and leakage rate of each segment. When the segments are assembled and the locomotive is supplying air, the air flow method is more expedient than the leakage method for testing the train. This procedure is efficient, but it relies on being able to project the gradient and air flow of the train before assembly based on the gradients and leakage rates (or flow rates if available) of the individual segments. One additional complicating factor is that the segments are tested at a lower charge pressure (typically 75 or 80 psi) compared to an assembled train (90 psi).

Previous work in this area has shown that the relationship between leakage rate and air flow is not a simple one and depends on multiple variables including leak orifice size, consist length, and brake pipe charge pressure.[2,3] Gradient is heavily dependent on where the leaks are located in the train. This digest builds on the relationships among the relevant variables established previously by proposing a method to use regression equations to quantitatively predict train gradient and flow rate based on the measured gradient and leakage rates of train segments.

TEST DETAILS

The air brake laboratory at the TTC contains the braking system of a freight train up to 150 cars including a 26-L brake valve to control charging and brake applications. Shorter consist lengths can be tested by closing one of the angle cocks. The valves on each car can be cut-in or cut-out of the system. Figure 1 shows a view of the air brake lab.

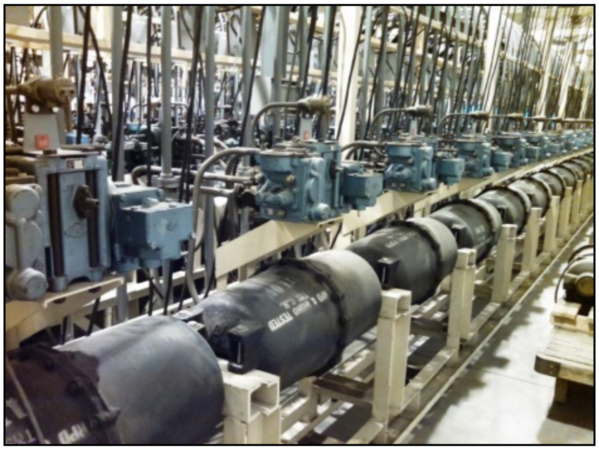

Figure 1. Air Brake Laboratory at the TTC

Intermediate pressure taps were installed throughout the train. These pressure taps were used to install pressure transducers and leaks at different locations in the train. Flow meters were installed in the piping before the first car in the consist.

The test procedure was designed to obtain values for the standard flow rate and leakage tests using a predetermined test matrix. Parameters varied in the test matrix were consist charge pressure, consist length, number of leaks, and location of leaks. Measured parameters included flow rate at the head of the train and pressure at four locations distributed evenly in the consist. Tests consistently had all control valves cut-in.

Leaks were created by placing 3/8-inch elbows with a pneumatic fitting into quick release valves. The flow rate of the leak was limited by the diameter of the pneumatic fitting and was roughly 15 cfm per leak at a charge pressure of 75 psi. Leaks were located at 0, 50, or 100 percent from the head end. For all test cases, the leaks were placed within the limits of the front and rear pressure transducers. The head pressure transducer was in the first possible valve upstream, and the rear pressure transducer was in the last possible valve in the given consist.

Figure 2 illustrates pressure readings from the head and rear of the train in response to the test procedure. First, the charge pressure and consist length were set. Leaks were then placed in brake pipe and the consist was charged. The consist was considered fully charged when it reached steady state, or when flow rate and pressure did not change significantly within 5 minutes. Once charged, data collection began. A 20 psi brake pipe pressure reduction was made based on the head pressure transducer. After the reduction, the system was allowed to reach steady state. The air compressor, or pressure maintaining feature, was then cut out of the system. Data collection continued for an additional 150 seconds to obtain the leakage rate after waiting 60 seconds. Raw data from each test was post-processed to obtain the results.

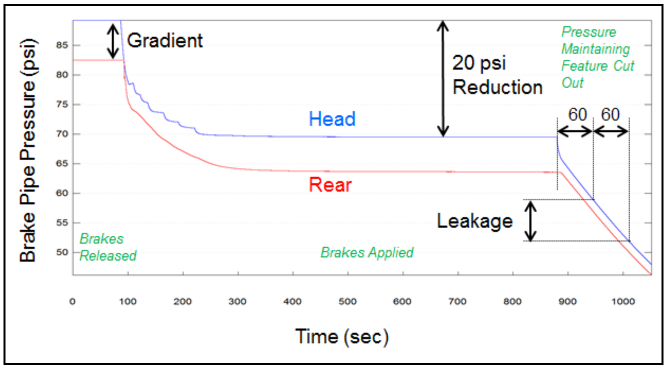

Figure 2. Example Data Illustrating Test Procedure and Extracted Values of Gradient and Leakage Rate 60-120 seconds

RESULTS

The test matrix resulted in a total of 81 runs from a combination of three charge pressures (75, 80, 90 psi), three consist lengths (20, 85, 150 cars), three leak locations (0, 50, 100 percent from head end), and three leaks (quantity 1, 2, or 3). Figures 3 and 4 are scatterplots at steady state and before the 20 psi reduction. In Figure 3, flow rate is plotted against charge pressure and grouped by number of leaks. The variation in each grouping is in part caused by different consist lengths and leak locations. In Figure 4, gradient is plotted against leak location in feet and grouped by number of leaks. Variation in each group of three points is caused by the three different charge pressures.

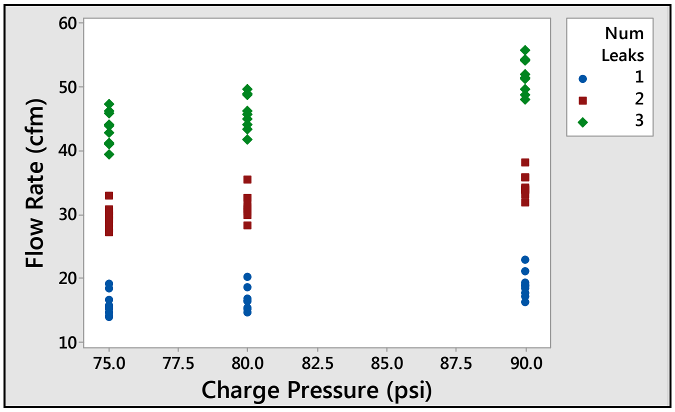

Figure 3. Scatterplot of Flow Rate vs. Charge Pressure

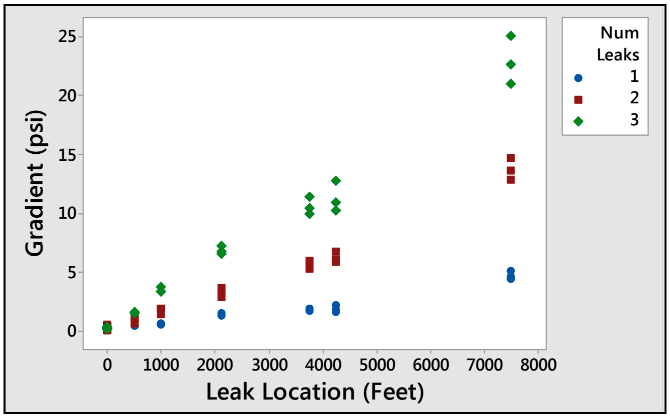

Figure 4. Scatterplot of Gradient vs. Leak Location

Regression analysis was performed on all data to develop useful relationships for individual train segments and for an assembled train. Input parameters are those obtained in a railroad yard for each segment including yard air pressure, length of consist (number of cars and total footage), gradient, and leakage rate or flow rate. Because gradient is highly dependent on the location of the leak within the train, another necessary input parameter is to note how the head end of the segment is placed into the assembled train. If the segments are yard tested from one end and pulled in the train from the other end, the relative location of the leak from the air supply could be substantially different. Table 1 demonstrates the structure of input parameters and predicted values for the individual segments. From the segment information and additional relationships, predictions are made for the assembled train as seen in Table 2.

Table 1. Individual Segment Input and Predicted Values

	Individual Segment No. and Order in Assembled Train				
Input	1	2	3	4	5
Yard air pressure (psi)	-	-	-	-	-
Length (No. of cars)	-	-	-	-	-
Length (ft)	-	-	-	-	-
Gradient (psi)	-	-	-	-	-
Leakage rate (psi/min)	-	-	-	-	-
Flow rate if available (cfm)	-	-	-	-	-
Head end is same as placed in assembled train (True/False)	-	-	-	-	-
Predicted	1	2	3	4	5
Estimated flow rate (cfm)	-	-	-	-	-

Table 2. Assembled Train Input and Predicted Values

	Assembled Train
Input	
Locomotive supply pressure (psi)	-
Predicted	
Estimated gradient (psi)	-
Estimated flow rate (cfm)	-

Regression equations were developed for individual segments and for the assembled train using a simplifying assumption that the sum of all leaks in the segment can be represented by a single concentrated leak. Previous work indicates that this is a reasonable simplification.[2] These equations include predicted flow rate (cfm), predicted leak location (ft), and predicted leak severity. Results for predicted leak locations and leak severity are not included in Table 1, but they are needed for predictions of the assembled train. Two regression equations were established for the assembled train. These equations included predicted gradient (psi) and predicted flow rate (cfm). The error of the predicted flow rate relationship is presented in Figure 5 by plotting predicted flow rate against the measured flow rate. The error of the predicted gradient relationship is shown in Figure 6.

Validation of the regression equations and Tables 1 and 2 was accomplished to a limited extent. Individual segments were designed and placed into different orders for the assembled train. The individual segments were each 50 cars long and had leaks placed at the tail end. Three segments were designed with three leaking conditions (quantity 0, 1, or 2). For the assembled train, the air flow predictions were typically within 10 cfm of the measured value, and gradient predictions were typically within 5 psi when using the measured leakage rate of the individual segments. When the measured air flow rate (rather than the predicted flow rate) was used for these individual validation segments, the predictions for the assembled train flow rate and gradient were more accurate: within 5 cfm and 2 psi, respectively.

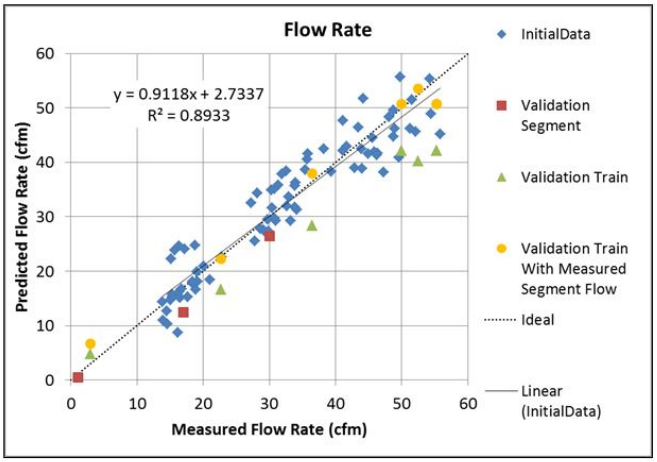

Figure 5. Predicted vs. Measured Flow Rate; Error is Difference from 1:1 Ideal Line

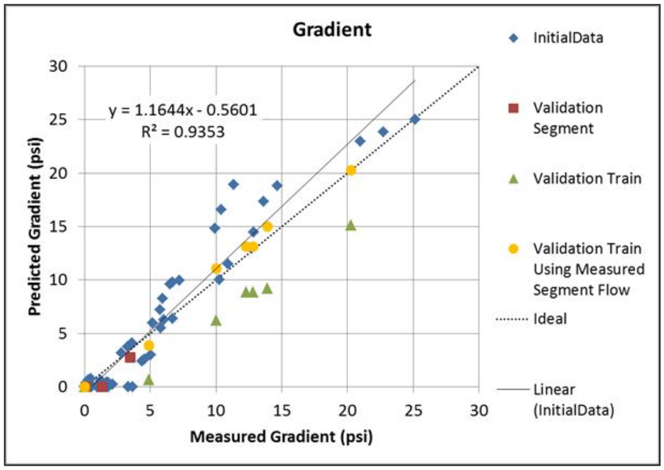

Figure 6. Predicted vs. Measured Gradient; Error is Difference from 1:1 Ideal Line

CONCLUSION

TTCI has generated regression equations to predict the air flow rate and gradient in an assembled train based on typical yard test values from individual segments of the train. The equations were based on 81 tests conducted in the air brake laboratory at TTC with a variety of charge pressures, consist lengths, leak locations, and leak severities. Limited validation testing showed air flow predictions were typically within 10 cfm of the measured value for the assembled train and gradient predictions were typically within 5 psi. These values improved to 5 cfm and 2 psi, respectively, when measured air flow for individual segments was used.

NEXT STEP

TTCI has distributed a spreadsheet to AAR member railroads containing the regression equations and a simple interface with the input and predicted values shown in Tables 1 and 2. TTCI will await any further action based on feedback from the railroads over the winter when brake systems typically experience more leakage.

REFERENCES

1. Federal Railroad Administration. “Class I brake test – initial terminal inspection,” Code of Federal Regulations, Title 49 Part 232.205.
2. Hart, J. 1987. “Brake Pipe Leakage, Air Flow, and Gradient in Freight Trains.” *Air Brake Association Convention Proceedings*, Chicago, Illinois.
3. Aronian, A., K. Carriere, and E. Gaughan. 2014. “Train Qualification in Extreme Cold Temperatures.” *Air Brake Association Convention Proceedings*, Montreal, Quebec.