Research and Test Department

Undesired Emergency Brake Applications Transportation Test Center UDE Tests

Report No. R-761

F. G. Carlson

Chicago Technical Center

ASSOCIATION OF AMERICAN RAILROADS

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13. ABSTRACT

This report covers the Federal Railroad Administration funded Undesired Emergency Tests performed at the Transportation Test Center in Pueblo, Colorado. This report also covers the AAR research conducted prior to the Transportation Test Center tests. This is necessary in order to provide a background to better understand why the test was designed as it was.

The FRA Undesired Emergency Test proved that pressure fluctuations of up to 2 psi can occur due to slack action alone, independent of any intentional brake applications. Brake pipe pressure reduction rates of over 30 psi/sec lasting for about 15 milliseconds were created by harsh slack run-ins. These rates are very close to those necessary to produce Undesired Emergency Brake Applications.

A possible cure to Undesired Emergencies was tested. The use of a 0.43 inch dia. choke between the pipe bracket and the emergency portion of the control valve has been proven in lab tests to slightly reduce the sensitivity of a control valve to rapid short duration pressure reductions caused by slack action. The use of this choke in actual train tests resulted in no loss of normal desired emergency braking response.

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EXECUTIVE SUMMARY

Undesirable Emergency Brake Applications (UDEs) have been a continuing and elusive problem for the American railroad industry for the last 50 to 60 years. This problem has been the subject of an AAR Research and Test Department project since 1983. In 1988, the project neared completion with a Federal Railroad Administration funded train test conducted at the Transportation Test Center in Pueblo, Co.

During this time 10 in-service train tests have been conducted on the Canadian Pacific, the Santa Fe and the Chicago and North Western Railroads. A total of 18 control valves have been positively identified as having initiated UDEs from these test trains and from other sources. Of these 18 control valves, only 2 were found to be defective. Of the remaining valves, all were in operating environments which exhibited rapid, short duration brake pipe pressure reductions either due to the use of Locotrol (a radio controlled slave locomotive consist located near the center of the train) or to possible harsh slack run-in conditions.

The results of all research conducted thus far points to harsh slack action as the primary cause of UDEs. The FRA UDE tests have proved that brake pipe pressure reductions of up to 2 psi can occur due to heavy slack run-ins without any intentional service brake applications. Rapid short duration reduction rates of over 30 psi/sec for 15 milliseconds were recorded, and these rates have been proven capable in lab tests of producing UDEs.

Lab tests have also shown that a 0.43 inch dia. choke placed between the pipe bracket and the emergency portion of the control valve will slightly de-sensitize a control valve toward rapid short duration brake pipe reductions. This choke, when tested on the FRA UDE test train, had no significant effect on the normal response of intended emergency brake applications. Therefore, the pipe bracket choke is a promising cure for most UDEs.

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ACKNOWLEDGMENTS

Train Tests

The AAR would like to thank the the Canadian Pacific Railway, the Atchison, Topeka and Santa Fe Railroad, Trailer Train and the Chicago and North Western Railroad for their invaluable and ongoing aide and assistance with the train tests. We would also like to thank D.J.Manconi, Asst. Manager, Track/Train Dynamics, CP Rail, for his development of the Transparent Detector Unit, without which we probably would not have found any UDE initiating control valves.

Special thanks are due to the men who made up the test crews. These men spent many irregular and uncomfortable hours preparing and riding the test trains.

CP Tests;

D. G. Blaine - AAR

G. E. Cobden - CP Rail (WABCO Ltd. during the test)

M. Gelush - CP Rail

T. E. Goldblatt - AAR

R. Jennings - CP Rail

P. Layland - CP Rail

T. McCabe - WABCO Ltd.

W. R. McGovern - AAR

S. Short - CP Rail

T. Wojick - CP Rail

ATSF Tests;

R. S. Baker - Southern Pacific

M. J. Bell - ATSF

D. G. Blaine - AAR

J. Cassidy - Westcode

E. Cook - ATSF

R. P. Gayfer - WABCO

T. E. Goldblatt - AAR

R. Habegger - ATSF

R. D. Irby - ATSF

D. Means - WABCO

W. R. McGovern - AAR

J. R. Mecaskey - ATSF

R. B. Morrison - ATSF

D. E. Palmer - New York Air Brake

W. Rawlins - ATSF

C&NW Tests;

M. X. Arkelian - C&NW

D. D. Anderson - C&NW

D. G. Blaine - AAR

J. Cassidy - Westcode

D. D. Hed - C&NW

C. Hosmer - WABCO

W. R. McGovern - AAR

D. E. Palmer - New York Air Brake

M. F. Smith - C&NW

The help given by the New York Air Brake Co., the Westinghouse Air Brake Co., and WABCO Ltd. was invaluable. They unselfishly participated in single car and train rack testing. These people are:

B. W. Shute - NYAB

D. E. Palmer - NYAB

W. W. Banker - NYAB

R. W. Donovan - NYAB

C. D. Wright - WABCO (retired)

J. E. Hart - WABCO

D. G. Scott - WABCO

E. E. Allen - WABCO

T. B. Hill - WABCO

P. Flynn - WABCO Ltd.

R. W. Bartlett - WABCO Ltd.(retired)

Rob Gayfer - WABCO Ltd.

The following railroads contributed cars to the FRA funded train tests at the Transportation Test Center at Pueblo, Colorado;

Atchison, Topeka and Santa Fe

Canadian Pacific

Chicago and North Western

CSX Transportation

Norfolk Southern

Southern Pacific

Burlington Northern

Denver and Rio Grande Western

In addition, Knorr Bremse and Westcode were very helpful to the AAR staff, as were the many un-named carmen, train crew, and others who contributed to the running of all the tests.

Last, but not least, the AAR would like to thank the Federal Railroad Administration for their support of the UDE tests at the Transportation Test Center. Without their aid, these tests would have been much more difficult.

1.0 INTRODUCTION

Undesirable emergency brake applications (UDE's) have been a continuing problem to the railroad industry almost since the inception of the AB type control valve. A UDE is defined as an undesired emergency brake application usually but not always occurring during a service brake application. For the purposes of this study, a UDE is not defined as an emergency application resulting from a hose separation or any other known cause. These can be classified as desired emergency applications resulting from undesired hose separations. The UDE problem has been investigated off and on by various people since the late 1930's with little success. The development of the ABD type control valve did reduce the UDEs associated with the horizontal emergency piston orientation in the AB valve. However, UDEs continue to be a problem, and in the last ten to fifteen years have seemed to be on the increase. This report will cover the entire UDE study up to the conclusion of the FRA funded TTC UDE Test.

2.0 THEORY

2.1 UDE Characteristics

Some initial theories and characteristics have been developed by members of the railroad industry and air brake manufacturers as to the cause of UDEs. Some of these are:

1. UDEs typically occur at the beginning of or at the end of a minimum service application.

2. UDEs tend to occur when the brakes have not been applied for long periods of time. The widespread use of the dynamic brake as a service brake has resulted in much longer periods of time between brake applications.

3. Long cars are more likely to have UDEs.

4. Moisture in the brake pipe acting with the outside environment causes UDEs.

5. Vibration causes the emergency slide valve to "settle" more tightly than normal onto its seat. This raises the static coefficient of friction between the valve and its seat. When the brake is applied, the force necessary to overcome this higher static friction forces the emergency piston to "overshoot" the service position and go to the emergency position. This is known as the "stiction" theory.

6. Localized, intermittent brake pipe leakage may cause a UDE. This could be due to tractive or braking forces, slack action, or curve negotiation opening a temporary leak in the brake pipe during a service application.

2.2 Emergency Portion Operation

Before delving into the UDE problem in detail, it is desirable to have a basic understanding of the operation of the emergency portion of a control valve. Exhibit 2.1 is a representation (known in the air brake industry as a diagramatic) of the emergency portion of an ABD control valve in release and recharge position. Only those components which have a direct bearing on emergency applications are included. These are the diaphragm controlled emergency piston, the emergency slide valve, the quick action chamber (QAC) charging choke, the QAC breather choke and the spill-over check valve. When charging, the brake pipe air is fed from the pipe bracket filter to the top of the emergency piston. It also feeds slowly through the small QAC charging choke (0.020 inch diameter) to fill the area beneath the emergency piston, the bottom of the spill-over check valve and the 162 cubic inch quick action chamber located in the pipe bracket. The air pressure in the quick action chamber is also the primary force acting to seat the emergency slide valve. Emergency reservoir pressure is fed to the top of the spill-over check valve. When the valve is fully charged in the release position all pressures are equal to brake pipe pressure.

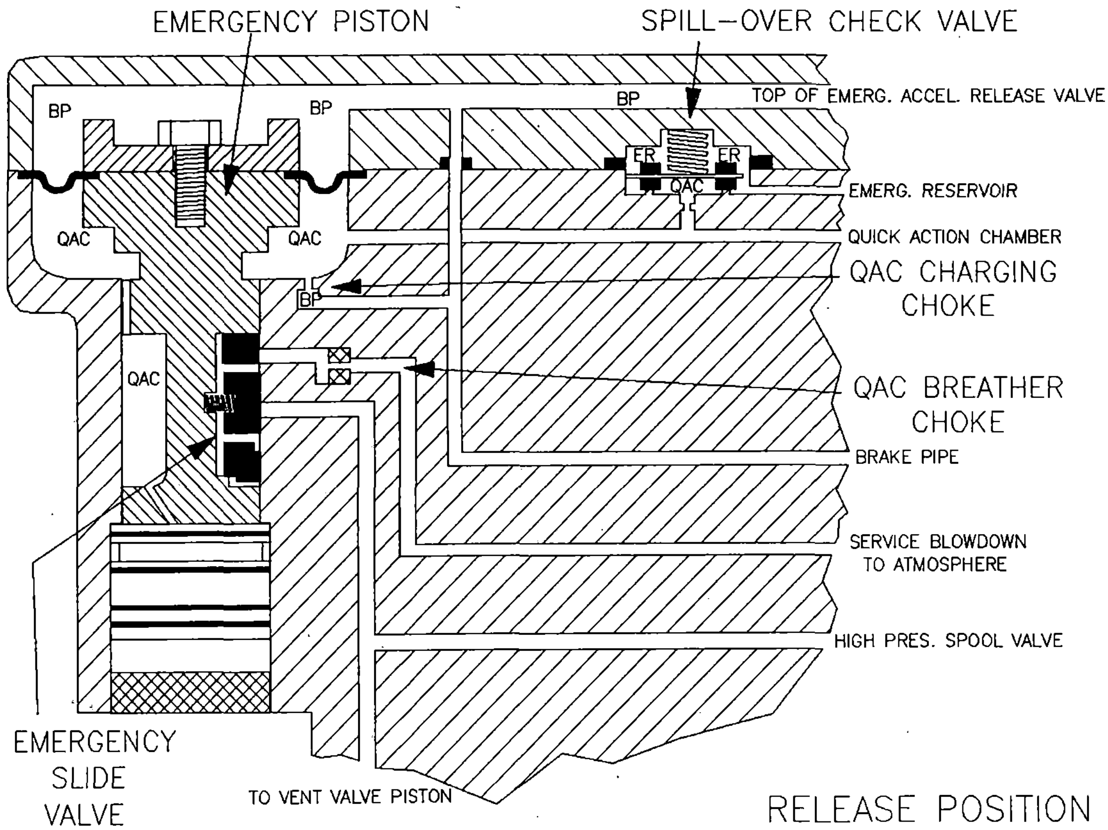


Exhibit 2.1

2.2.1 Service Position

When a service brake application is made, the brake pipe air pressure is reduced at a service rate which rarely exceeds 9 psi/second during quick service, and is normally under 5 psi/second. As the brake pipe pressure is reduced, the QAC air pressure remains essentially at the initial brake pipe pressure because the QAC air is bottled up behind the very small QAC charging choke. This creates a pressure differential across the emergency piston diaphragm, which causes the piston to move upwards into service position (Exhibit 2.2).

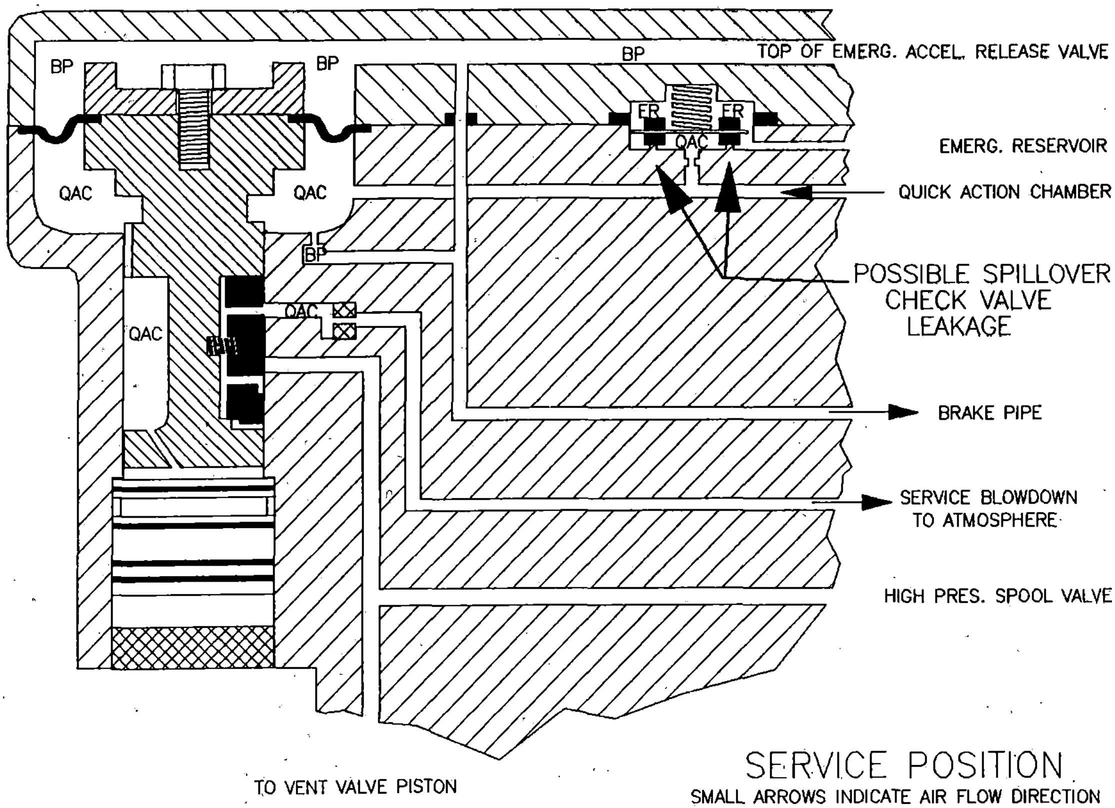


Exhibit 2.2

The emergency slide valve moves with the emergency piston and opens the service port which bleeds QAC air to atmosphere at a service rate through the 0.081 inch diameter QAC breather choke. The emergency piston will continue to float in the service region as long as the brake pipe reduction continues at a service rate. When the brake pipe reduction stops, the QAC will continue to bleed to atmosphere until its pressure is below brake pipe pressure. This creates a pressure differential forcing the piston downwards to release position, where it remains until the next service reduction.

2.2.2 Emergency Position

If the brake pipe pressure reduction is at a higher than service rate, the QAC breather choke is no longer able to exhaust QAC air fast enough to prevent a build-up of a pressure differential across the emergency piston. When this occurs, the piston continues to move upwards to emergency position (Exhibit 2.3). When the slide valve reaches emergency position, the service port is closed off and the emergency port is opened. This allows the QAC air pressure to reach a piston which opens the brake pipe vent valve. When the pressure on the vent valve piston reaches about 32 to 36 psi, the piston rapidly opens the vent valve, which rapidly exhausts the remaining brake pipe air to atmosphere. The emergency slide valve also allows the QAC air pressure to reach the bottom of the high pressure spool valve, moving it upwards to emergency position and making the port connections between the emergency reservoir and the brake cylinder.

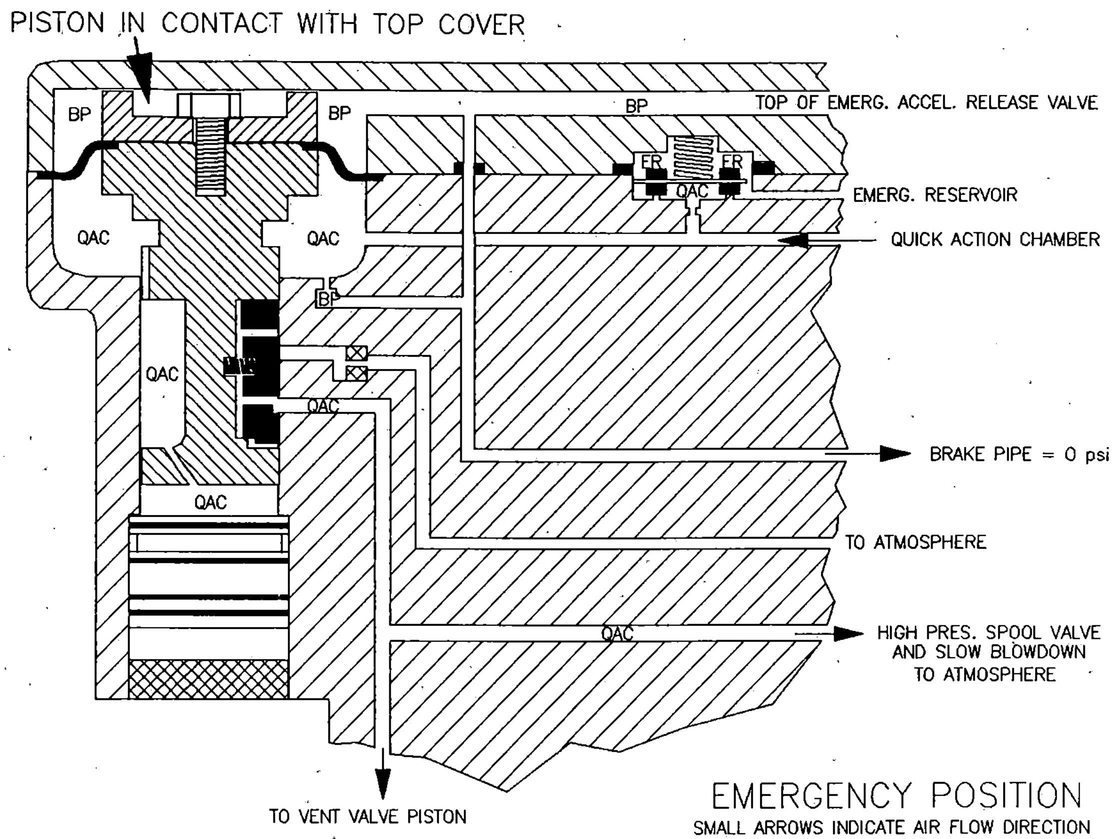


Exhibit 2.3

The high pressure spool valve is not represented in the diagramatics since it has no significant effect on the operation of the emergency vent valve and the propagation of emergency applications. If the high pressure spool valve should stick in service position, the only result will be no build-up of emergency brake cylinder pressure, and if the spool valve should stick in emergency position, there will be a constant blow of air at the retaining valve and the control valve will not fully charge. After the emergency piston reaches emergency position, the QAC air pressure is slowly bled to atmosphere through a 0.020

inch diameter choke. When the QAC pressure reaches about 10 psi, which takes about one minute, the emergency vent valve is closed by a spring and the brake pipe and control valve can be re-charged.

3.0 CANADIAN PACIFIC TESTS

In 1983, the AAR at the behest of the AAR Implementation Officers initiated a UDE study under the Track Train Dynamics Program. Up to the end of 1984, the study was frustrated by an inability to positively identify a control valve or cause which had initiated a UDE on an in-service revenue train. Early in 1985, The Canadian Pacific informed the AAR of a serious UDE problem with the unit coal trains operated on the Pacific Region of the CP. The number of CP reported UDEs increased dramatically during the early Fall and late Spring seasons. The CP also developed a method to positively identify the car which initiates a UDE (a "kicker"), and arrangements were made to conduct road tests using in-service revenue coal trains during May of 1985. The objective of these tests was to identify as many "kickers" as possible, and subject these valves to detailed investigation on train test racks, AAR single car test racks, and AB test racks.

3.1 INSTRUMENTATION

Two methods were tried to identify a kicker. The first was an AAR supplied device called an Undesired Emergency Locator (UEL). This consisted of two radio equipped instrumentation packages, one of which was mounted on the locomotive and the other in the caboose. Each was connected to a pressure transducer to sense brake pipe exhaust at the exhaust port of the emergency portion on the last car, and the vent valve on the lead locomotive. When one of the units sensed a blast of air from the emergency vent valve due to an emergency application, it would radio this signal to start a timer in both units. When the other unit sensed the emergency, the timer would stop in both units, and by knowing the length of brake pipe in the train, and which unit sensed the emergency first, the device would compute the distance from the head end to the kicker. At the AAR Transportation Test Center (TTC) in Pueblo, the UEL could locate a kicker within two to three car lengths. On CP's route, this method proved unsuccessful due to the UEL's requirement for line of sight radio communication during the several seconds of emergency propagation (about 9 seconds on a 7000 foot train), and the lack of same due to rugged mountain terrain.

The second method was developed by D. Manconi, Director - Track Train Dynamics of the CP, and was ultimately successful. It is called the transparent detector unit (TDU), and it is pictured in Exhibit 3.1. It consists of a short length of clear plastic high pressure hose with a hose coupling at each end. Inside the hose and anchored to one of the hose couplings is one end of a flexible ribbon. The ribbon acts as a flag which follows the direction of air flow. Since the air in the brake pipe tends to run toward the kicker, the kicker can be found by coupling a TDU between every car in the train, and observing the direction of the flags after a UDE has occurred. This method is most successful when a fixed consist is reported to have a high number of UDEs, as in the CP case.

TRANSPARENT DETECTOR UNIT (TDU)

developed by CANADIAN PACIFIC

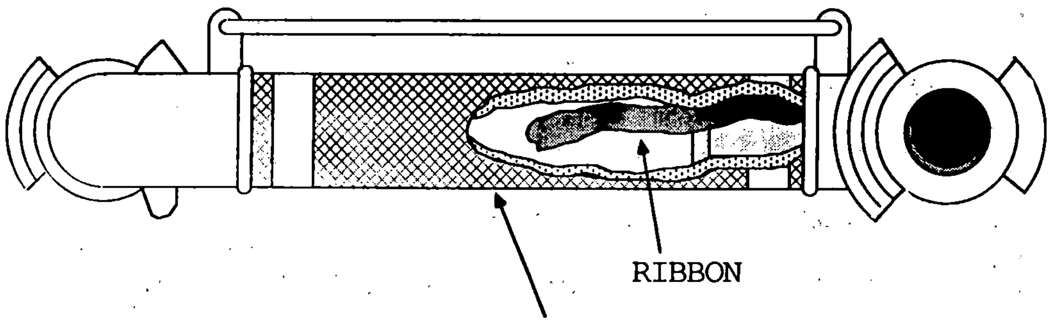


Exhibit 3.1

3.2 TEST PROCEDURE

The test train was a 110 car unit coal train equipped with Locotrol II. The power consisted of three lead units, and two remote units located 47 cars back in the train. A train with a very bad record of UDE's was chosen. On 5/10/85, the train was equipped with TDU's between every car and with the UEL. The emergency magnet valve on the Locotrol II remote unit was disabled to prevent any false readings due to Locotrol initiated emergencies from the middle of the train. The test consisted of riding the empty train from the dumpers at Roberts Bank (near

Vancouver) to Fort Steele and return to Roberts Bank with the loads. Minimum service brake applications were made at intervals of 45 to 90 minutes. If a UDE occurred, the test crew walked the train, observed the TDU's, and thus determined the exact location of the kicker. The UEL was to give a readout of the location of the kicker in feet of brake pipe from the head end, but it was never successful.

3.3 CP TEST RESULTS

Out of a total of 34 service brake applications in the 611 miles from Roberts Bank to Fort Steele, 9 car air brake valve initiated UDE's were experienced. From these UDE's, seven control valvs were positively identified as kickers. After these cars were removed from the train or cut out, no further UDE's occurred during the loaded return portion of the trip. Six of these cars were located between car 19 and car 36, or at roughly the mid point between the lead and remote units. The seventh car was the last car ahead of the caboose. Because of the loss of radio signal due to the rugged terrain, the UEL was unreliable.

The fact that six of the seven confirmed "kickers" were located at the midpoint between the lead and remote units raised the possibility that in the CP's case the remote Locotrol II units are being operated too close to the lead units. This theory states that if the service brake pipe reductions from the lead and remote units meet at the midpoint between the lead and remote units, and that happens to be at a branch pipe location, a larger than normal service reduction can occur and cause a valve to go into emergency.

The cars were given AAR single car tests at Revelstoke, with the service stability portion of the test repeated as many as eight times. Of the seven cars tested, only three failed the service stability test, and they only failed once after repeated tries. Both portions of the seven control valves were then removed from the cars and given AB rack tests at CP's Ogden Shops in Calgary. Exhibit 3.2 lists the pertinent information on each valve plus the number of UDEs attributed to each valve. Exhibit 3.3 lists the results of the single car tests at Revelstoke and the AB shop rack tests at Calgary.

Exhibit 3.2

CAR #	LOC IN TRAIN	BLT**	COTS**	IDT**	VALVE TYPE	IN SERV. YR-MO	# UDEs DURING TEST
UNPX 100392	29	6/74	6/74	1/24/84	ABD	10-11	1
UNPX 102342	110	12/75	12/75	5/3/85	ABD	9-6	2
UNPX 102476	33	1/76	10/84	NONE	ABD	0-7	2
UNPX 102609	32	12/80	12/80	10/21/81	ABDW	4-6	1
CP 349192	20	1/70	4/76	3/25/85	ABD	9-1	1
CP 351442	29*	1/72	2/80	1/10/85	ABD	5-3	2
CP 351549	35	2/72	12/78	3/5/84	ABD	6-5	1

* This car replaced UNPX 100392 in the east bound test train at Revelstoke.

** <u>BLT</u> refers to date the car was built, <u>COTS</u> refers to the date when the car was last Cleaned, Oiled, Tested and Stenciled, and <u>IDT</u> refers to the date when the car last recieved an In Date air brake test.

Exhibit 3.3

CAR #	LOC. IN TRN	VALVE TYPE	SERVICE EMERGENCIES	SINGLE CAR STABILITY TEST # of TRIES	AB RACK TEST RESULTS
UNPX 100392	29	ABD	0	8	High pres. spool valve stuck. Static friction was 24 lb. Valve was disassembled.
UNPX 102342	110	ABD	1	3	Failed serv. stability test 6 out of 8 times.
UNPX 102476	33	ABD	0	5	Passed serv. stability 7 out of 7 times.
UNPX 102609	32	ABDW	1	3	Passed serv. stability 10 out of 10 times.
CP 349192	20	ABD	0	8	Passed serv. stability 7 out of 7 times.
CP 351442	29(2nd)	ABD	0	5	Passed serv. stability 7 out of 7 times.
CP 351549	35	ABD	1	8	Passed serv. stability 7 out of 7 times. HP spool valve stuck in up position. Reset at 10 psi.

It should be noted that the only control valve which failed the AB rack service stability test was the valve from the 110th car. None of the remaining valves were defective on the AB test rack. It should also be noted that the stuck high pressure spool valves have no effect in making a valve go to emergency. The only function of the high pressure spool valve is to connect the emergency reservoir to the brake cylinder and to ensure blow down of the quick action chamber <u>after</u> the valve has gone into emergency. In actual operation, after a release from emergency, there is normally an ample force from the rising brake pipe pressure to move the high pressure spool valve down to the normal position.

The disassembled valve showed no signs of rust or excessive dirt or coal dust. Lubrication appeared to be in good condition. When the high pressure spool valve was freed, it worked properly in its bore.

When the AB test rack tests were completed, the valves were distributed to the New York Air Brake Co. (NYAB), the Westinghouse Air Brake Co. (WABCO), and to the AAR Chicago Technical Center (CTC) for further testing.

3.4 NEW YORK AIR BRAKE TESTS OF CP VALVES

3.4.1 TRAIN TEST RACK UDE TESTS

Both portions of the control valves from car 20 and car 29 were sent to NYAB for testing on their 150 car air brake test rack. The test rack was configured to duplicate the test train as closely as possible, and the test valves were mounted on the rack in their test train positions. The function of the Locotrol II lead and remote units was also duplicated. The remote units were initially located 49 cars back from the head end, and later were moved to car 35. The purpose of these rack tests was to try to duplicate a UDE under laboratory conditions and to check out the possibility that CP is operating their remote units too close to their lead units.

No UDE's resulted from these tests. Exhibit 3.4 shows a plot of brake pipe pressure at various points in the train during a minimum brake application. Note that the quick service action was most pronounced at the mid point between the lead and remote units, and at the rear of the train. The remote units showed a surprising lack of quick service activity. Repeated minimum and full service applications were made with the remote unit's feed valve cut in and cut out, and no UDE's occurred (with the remote unit's feed valve cut out, the train brakes behave conventionally). When emergency applications were intentionally made, the brake pipe reduction rates which caused a particular valve to go to emergency were about 35psi/second for time intervals of 0.1 second.

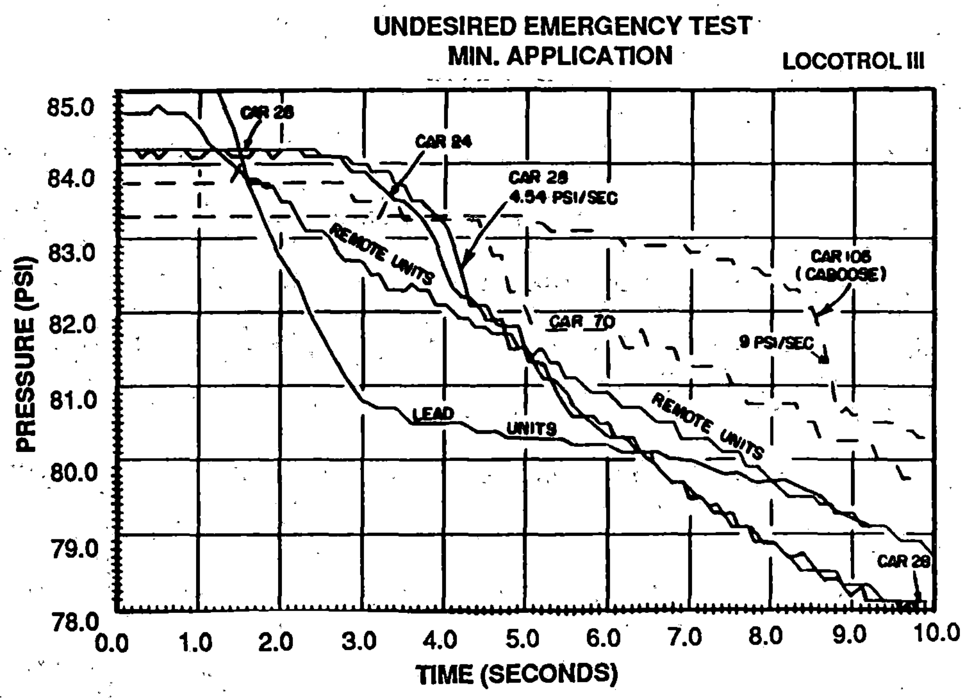


Exhibit 3.4

Plot of BP Pressure vs. Time - NYAB 150 car rack test

Minimum application with remote unit feed valve cut in

3.4.2 TRAIN TEST RACK CONCENTRATED LEAKAGE TESTS

In order to investigate the theory of UDE's being caused by momentary stretch brake pipe leakage, the valve from car 28 was put on the 150 car rack, and leakage was introduced at the car 28 location. A worst case situation was duplicated by opening a choke at the same time as the service pressure wave reached car 28. The CP standard brake pipe pressure of 85 psi was used.

In order to get the train to go into emergency, a 1/4 inch NPT (National Pipe Thread) opening (roughly equivalent to a 3/8 inch diameter orifice) was required in addition to a minimum service application. This is a substantial leak, and is unlikely to occur in everyday railroad service.

3.4.3 TESTS ON SINGLE CAR TEST RACK

Both test valves and a typical control valve taken from the 150 car test rack were given single car service stability tests at ambient and freezing temperatures. An X-Y plotter was used to record the brake pipe pressure during the tests. The tests were made at both 70 and 85 psi brake pipe pressures. One of the valves was allowed to cold soak overnight at 30 degrees F. The cold chamber's dryer was disconnected for all tests. An AAR standard single car test device was used to make the brake pipe reductions. About six feet of 3/4" hose connected the device to the pipe bracket. The test valve was mounted inside an environmental chamber, which incorporated an 800 cu.in. volume roughly equivalent to 54 feet of brake pipe.

Using air brake manufacturers terminology, a valve must remain stable in service when the brake pipe pressure is reduced from 70 to 50 psi in 1.4 seconds, and the valve must go to emergency (unstable) when the rate is 1.2 seconds for the same pressure drop. In other words, a maximum stable reduction rate of 14.3 psi/sec must produce a service application, and a minimum reduction rate of 16.7 psi/sec must produce an emergency application. The reduction rates recorded during service stability tests at 70 psi brake pipe pressure were 8.5 to 9.0 psi/sec for about 0.5 seconds. These rates are much slower than the 14.3 psi/sec no-go rate. This is also considerably below the 35 psi/sec rate required to put the test valves into emergency on the 150 car test rack. None of the valves tested on the single car test device failed the service stability test at either room temperature or at 32 degrees F.

3.5 DISCUSSION OF NYAB TESTS

In view of the fact that six of the seven kickers were located between the lead and remote units on the test train, it was expected that the 150 car test rack would show high brake pipe rates at that location. Instead, the reduction rates between the lead and remote units were about 4.5 psi/sec. In addition, the lack of quick service activity at the remote unit was surprising. Because of this, and the failure to generate any UDE's, it became apparent that the 150 car rack test might not have accurately simulated the actual in-service train conditions. It was decided that field test data on an actual CP Locotrol II equipped unit coal train would be necessary to validate the 150 car rack test results.

The single car tests, while inconclusive, did establish the possibility that the service stability portion of the single car test is inadequate. It was decided to establish the rates necessary to initiate an emergency for a wide assortment of new and in service control valves, and use this data to try to establish a more realistic service stability rate.

3.6 WABCO TEST OF CP VALVES

3.6.1 TESTS ON SINGLE CAR TEST RACK

In light of the NYAB experience, it was decided to concentrate on the performance characteristics of each individual test valve using a single car test rack. The valves received by WABCO for test were from cars 32, 35, and 110. All of these valves failed the single car service stability test once in 3 to 8 tries. Only the valve from car 110 failed the AB rack service stability test at Ogden Shops. It failed six out of eight times. Prior to the tests, WABCO ran all three valves through the service stability test on the AB test rack. Interestingly, all passed the standard AAR AB test rack service stability test. Valves 32 and 35 passed and valve 110 failed the in-house WABCO AB rack service stability test, which is 10% faster than the AAR test.

3.6.2 INSTRUMENTATION

The tests were conducted on an AAR standard single car test rack, with 46 feet of brake pipe. The brake pipe reductions were made using a standard single car test device equipped with an extra 3/8" exhaust cock. Various sized chokes were installed in the 3/8" cock to alter the brake pipe reduction rates. The emergency portion was mounted on a one inch thick filler piece.

Mounted on the filler piece were pressure transducers reading brake pipe and quick action chamber (QAC) pressure, which allowed pressure readings very close to the face of the emergency piston. This was connected to a data acquisition system capable of scanning the pressure channels at up to 500 scans per second. The print outs were plots of brake pipe pressure, QAC pressure, and the differential of these two pressures, which is the pressure differential across the emergency piston.

3.6.3 TEST PROCEDURE

The intent of these tests was to determine the actual go/no-go rates of these test valves. This was done by starting with a standard service stability test using position #6 of a standard AAR single car test device. Then, using the extra 3/8" cock, the choke size was increased until the valve went to emergency. This was done primarily with the CP Pacific Region standard brake pipe pressure of 85 psi, although some tests were done at 70 psi. Since the valves are rate sensitive, the difference in pressure made no significant difference in the results.

3.6.4 RESULTS

The results of these tests are given in Exhibit 3.5.

Exhibit 3.5

EMERGENCY BRAKE PIPE REDUCTION RATES

VALVE FROM CAR #	STABLE (NO GO) RATE psi/sec	STABLE (NO GO) TIME DURATION sec	UNSTABLE (GO) RATE psi/sec	UNSTABLE (GO) TIME DURATION sec
110	28.7	.05	27.5	.08
32	40.2	.05	40.8	.06
35	31.9	.07	34.7	.05

The service stability rates recorded during the AAR single car tests given to each valve are presented in Exhibit 3.6.

Exhibit 3.6

SERVICE STABILITY RATES

VALVE # (Car #)	INITIAL B.P. PRES. psi	S.S. RATE psi/sec
110	70	11.0
110	85	12.8
32	85	12.5
35	85	11.6

3.6.5 DISCUSSION

Examination of the data plots revealed that the valves went to emergency at relatively high brake pipe reduction rates over short time durations. Both air brake manufacturers felt that rates as high as 25-30 psi/sec would not be found in actual train service, and the NYAB tests revealed no reduction rates which even approached these test rates during service applications. The fact that these high reduction rates of short time duration were necessary to get these valves to go into emergency, and that these valves were definite confirmed kickers, indicated that these fast brake pipe reduction rates might indeed be present under actual train operating conditions. It was resolved that a road test consisting of recording brake pipe pressure and vibration at various points in the train under over-the-road operating conditions would be necessary. The test was scheduled for the Fall of 1985 on the same CP unit coal train service.

The service stability tests underscored the possibility that the AAR single car test is inadequate. While the 11.0 psi/sec rate achieved at WABCO is faster than the NYAB rate of 8.5 psi/sec, it is still below the 14.3 psi/sec maximum no/go rate. It should be emphasized that the traditional single car test procedures and exhaust choke orifices were based on a car with approximately 50 feet of brake pipe. On cars with longer brake pipe lengths, the service stability rate is an even slower and less critical test of the control valve. This is due to the fixed brake pipe exhaust chokes in each position of the AAR single car test device. On typical long 89 foot cars, typically with 110 feet of brake pipe, the present service stability test in position #6 is very far below the critical 14.3 psi/sec no/go rate. This may explain why long cars tend to have more UDE's; the bad acting, more sensitive valves are simply rarely found using the present single car service stability test. Because of this, it was decided to gather enough data to enable the design of a more effective service stability test, which would take brake pipe length into account.

4.0 SECOND CP TRAIN TEST

4.1 TEST PROCEDURE

The second series of train tests was carried out from Oct 28 to Nov 5, 1985, on the CP between Roberts Bank and Revelstoke, B.C. The tests were timed for late Fall to hopefully catch the seasonal rise of UDE's which the CP had been experiencing over the past seven years. The purpose of these tests was to find more "kickers", and to record brake pipe pressure reduction rates during brake applications hopefully on a car which initiated a UDE. An additional objective was to record vibration at the emergency portion of a control valve on a moving train.

4.2 INSTRUMENTATION

The instrumentation, pictured in Exhibit 4.1, consisted of a Campbell Scientific Data-Logger, which is a portable, battery powered, self contained data acquisition system. The Data-Logger was pre-programed to automatically take vibration and pressure data and record this data on a cassette tape recorder. For the over-the-road train tests, the brake pipe pressure transducer was installed in a special dirt collector bowl, which could be mounted on any car. Before the bowl was mounted on the car, the check valve was removed so that the resulting pressure readings were as close as possible to the pressure seen at the emergency piston diaphragm. A test conducted on WABCO's single car test rack showed no difference in brake pipe pressure reduction rates when read at the dirt collector bowl and at the emergency portion filling piece. For the standing train tests, the pressure transducer was screwed into a tee fitting and installed between the brake pipe hoses of adjacent cars. An accelerometer measured vibration in the vertical axis only, and was mounted on the emergency portion of the brake valve using one cap screw. The Data-Logger was mounted on an upright handrail using pipe clamps.

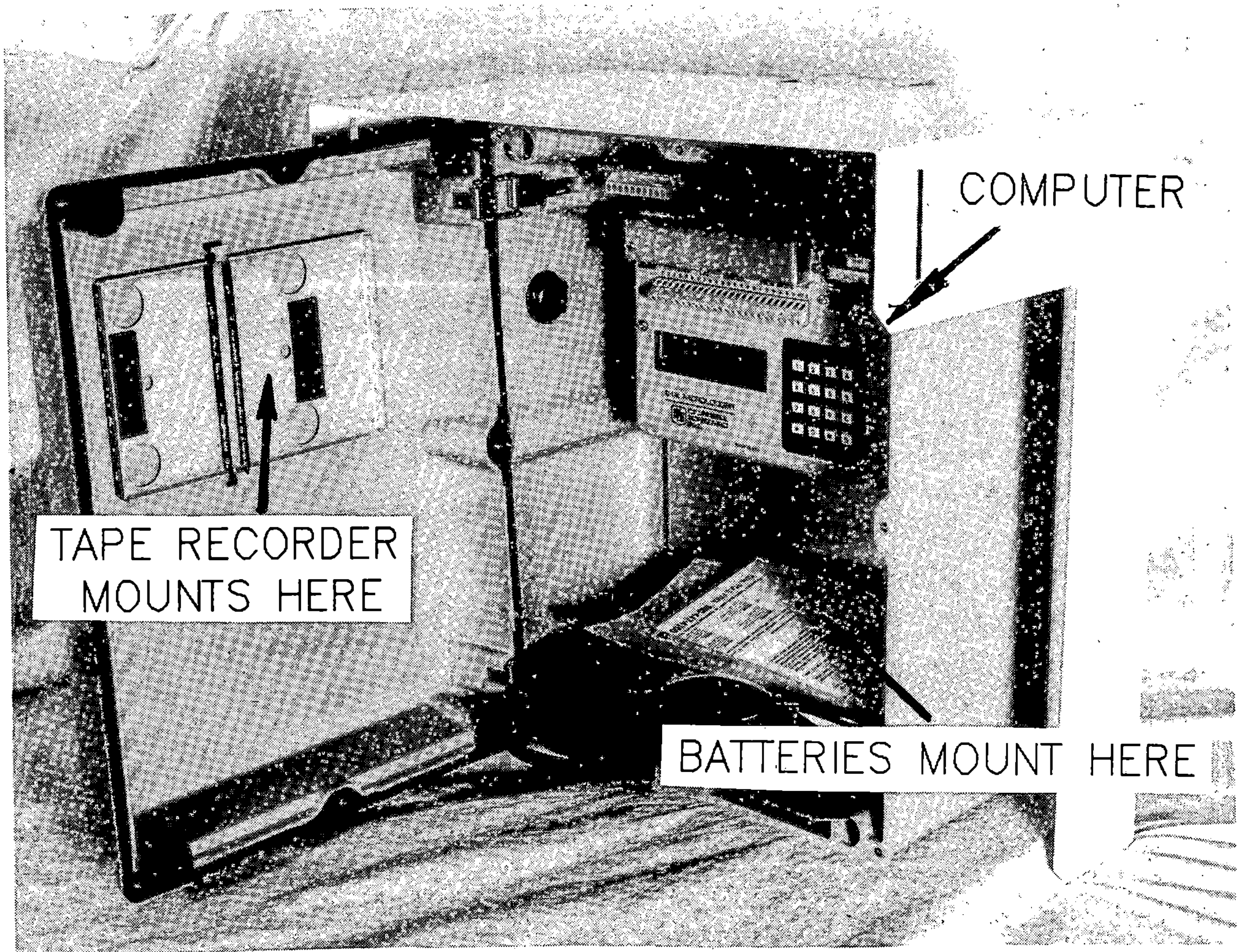


Exhibit 4.1

Data Acquisition System used on CP Tests

The raw data was checked on a Compaq IBM compatible computer carried in the caboose. At crew change points or at any other lengthy stop, the data tape was replaced with a fresh tape, and the data tape was played into the Compaq computer using a second cassette tape deck.

The Data-Logger program initiated the following series of events;

1. After the computer was turned on, it would scan brake pipe pressure until the brake pipe pressure rose above a trigger value (generally 4 psi below the fully charged pressure).
2. 15 minutes after reaching the trigger value, vibration data was recorded to tape at 256 scans per second.
3. The computer then went into an "idle" mode, and scanned brake pipe pressure at 500 scans per second. The data was temporarily stored in memory for ten seconds, and was constantly updated with more recent data.
4. When the brake pipe pressure fell below a second trigger value (generally 2 psi below the fully charged pressure), six seconds of data, plus the previous four seconds of data in the temporary memory, was taken and recorded on tape. This four second "look back" ensured that the start of the brake reduction would be recorded.
5. Unless the computer was manually turned off, it would then repeat steps 1 through 4.

4.3 STANDING TRAIN TEST RESULTS

At NYAB, a minimum reduction test with the remote unit's feed valve cut in showed maximum reduction rates of approximately 3.5 psi/sec at the 1st car, 4.5 psi/sec at the 28th car, and 9 psi/sec at the 110th and last car. The remote units showed no quick service action whatsoever, with a maximum rate of less than 1 psi/sec. The standing tests on the actual train were different. The remote units did exhibit quick service activity, and the 30th car had a maximum rate of 7.5 psi/sec, 66% faster than the NYAB test rack rate for the 28th car. The caboose had a maximum rate of 8.5 psi/sec, which agrees closely with NYAB's results. Maximum rates for full service reductions were not significantly different. Exhibit 4.2 shows the static test results compared with the NYAB data.

Exhibit 4.2

Maximum brake pipe reduction rates - minimum service reductions

Car Location	NYAB rate (psi/sec) Feed valve in	Static test rates (psi/sec) Feed valve in	Static test rates (psi/sec) Feed valve out
1	3.5	4.0	4.0
30 (NYAB 28)	4.5	7.5	2.2
45 (remotes)	1.0	3.3	1.0
110 (caboose)	9.0	8.5	7.8

Exhibit 4.3 shows graphs of the CP standing train test results for minimum reductions with the feed valve cut in and out. These graphs should be compared with Exhibit 3.4, which is a graph of the July NYAB train rack results for a minimum reduction with the remote feed valve cut in. In the standing train test graphs, the elapsed time required for the brakes to set up should be ignored. These curves were spaced out to approximate the NYAB graph for easier comparison.

When comparing the standing train test to the NYAB 150 car rack test it can be seen that the NYAB test was not necessarily a good simulation of the actual train.

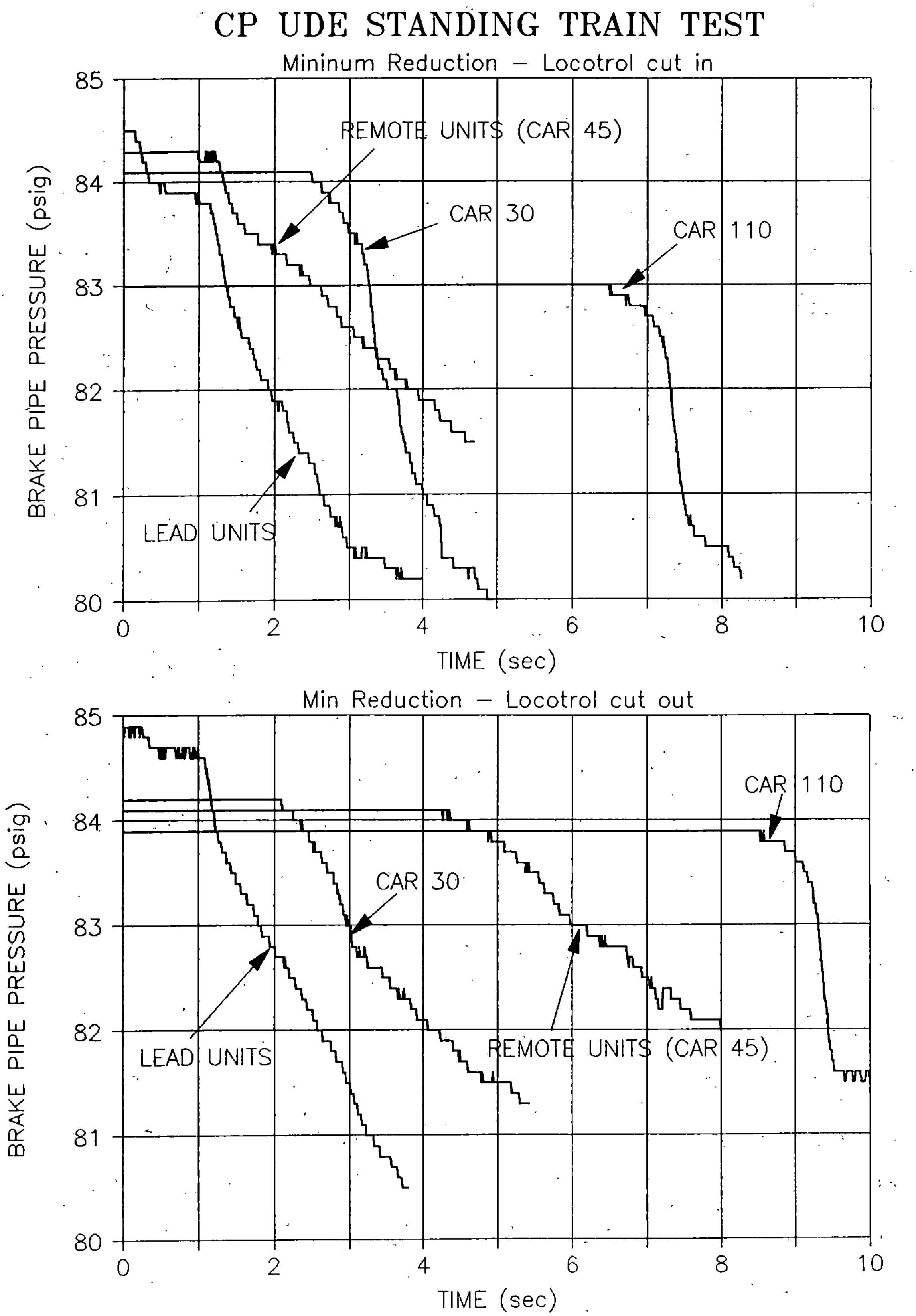


Exhibit 4.3
Minimum reduction on standing CP coal train
Remote unit feed valve cut in (top) and cut out (bottom)

4.4 SECOND CP TRAIN TEST RESULTS

4.4.1 BRAKE PIPE REDUCTION RATES

Brake pipe reduction rates were measured on three empty coal trains between Roberts Bank and Revelstoke. The instrumentation was mounted on car #116 for the 1st trip, car #28 for the 2nd trip, and cars #28 and #25 on the 3rd trip. The UEL was not used due to its ineffectiveness. the valve from car #110 of the May CP train test, which was the most sensitive valve tested at WABCO, was mounted on the instrumented cars for the 1st and 2nd trips. It was hoped that this valve would again initiate a UDE, and brake pipe pressure would be recorded during the event.

Two "kickers" were found on the first trip, and two more on the third trip. They were cars #28 and #23 on the first trip, and cars #24 and #25 on the third trip. All of the kickers were located at the midpoint between the lead and remote units, which again supports the theory that the Locotrol II remote units are too close to the lead units.

For as yet unknown reasons, the sensitive valve from the May train tests did not cause a UDE. Never during the tests did an instrumented car initiate a UDE. On the third test trip, after the valve on car #25 had twice caused UDE's, the instrumentation was moved to that car, and thereafter car #24 caused a UDE! As always, UDE's remain elusive. In addition, the pressure transducer failed during the UDE's of the third trip, but because of the remote location of the instrumentation, this was not discovered until too late. However, the recorded brake pipe pressure data yielded some surprises and answers, and raised some new questions.

Unlike the standing train tests and the NYAB train rack tests, the reduction rates for minimum reductions at the same car locations were not repeatable. The graphs of these reduction rates were analyzed for the short duration high rates which were found to be necessary at WABCO to initiate emergency applications. Exhibit 4.4 tabulates the maximum brake pipe reduction rates, their time duration, and the car location for all the minimum service applications for which good data was taken.

Exhibit 4.4

MAXIMUM BRAKE PIPE REDUCTION RATES

Car # Location of Instrumentation	B.P. Reduction rate psi/sec	Time Duration seconds	
116	11.4	.025	
116	11.8	.03	
116	22.2	.01	
116	11.0	.01	
116	11.1	.015	
116	22.2	.01	
116	12.8	.01	
28	10.9	.015	
28	11.9	.04	
28	20.0	.01	
28	11.1	.01	
28	31.25	.005	*
28	10.9	.05	
28	14.5	.02	#

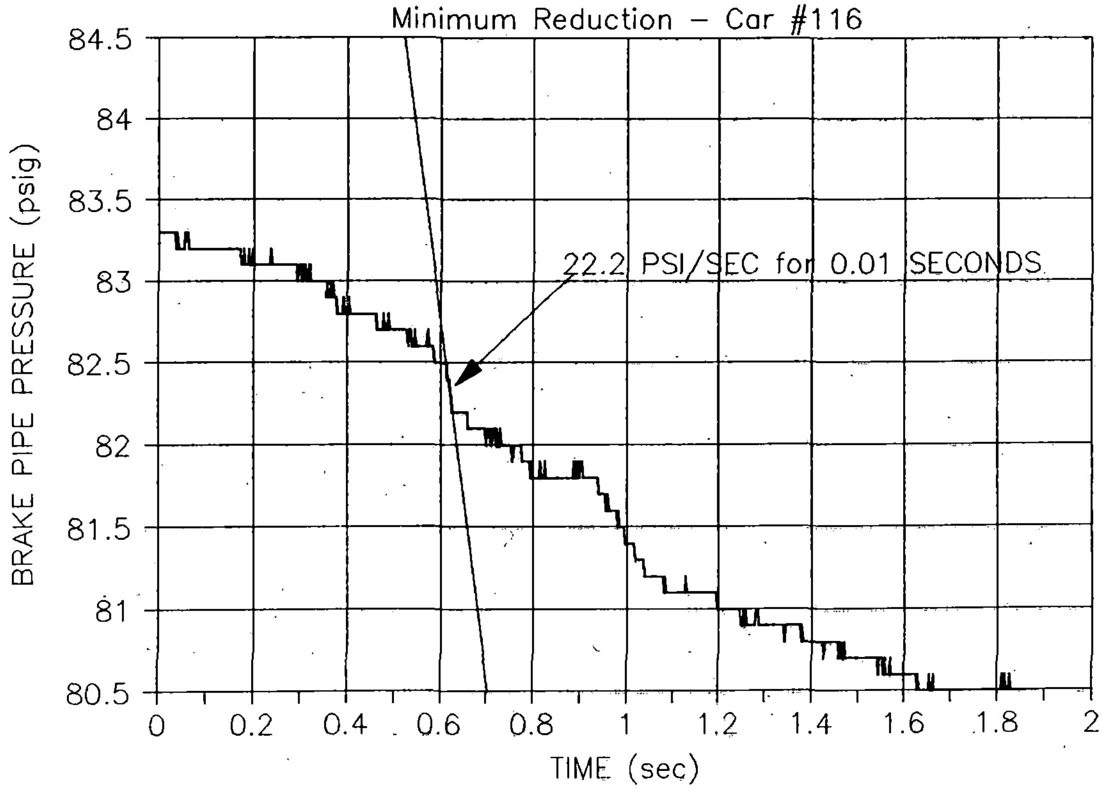
* These rates occurred during the same brake application
\# These rates occurred during the same brake application

Graphs of some of the maximum brake pipe reduction rates recorded on car #116 are shown in Exhibit 4.5. These curves are representative of the last car of a 70 to 80 car conventional train. Rates such as those depicted in the graphs were absent during some brake applications, and occurred once and sometimes twice in other brake applications. These rates in no way resemble the rates a valve experiences during the service stability portion of an AAR single car test, or during the shop test on an AAR AB test rack. Instead of the smooth pressure reduction rates of static tests, the train test graphs showed high reduction rates of short time duration during a brake pipe reduction, even though the overall average rates were similar.

4.4.2 DISCUSSION OF REDUCTION RATES

Exhibit 4.6 shows plots of the maximum reduction rates versus their time durations for car #116 and car #28. The service stability rate recorded on a car with 68 feet of brake pipe, like most of the CP coal gondolas, is plotted as a straight line. The area above the curve can be considered to be the range in which a valve will go to emergency. The rate which was needed to cause the sensitive valve from car #110 of the May test to go into emergency on the WABCO single car test rack is also included. It should be emphasized that the <u>service stability rates will decrease with longer brake pipe lengths</u>.

CP UDE TEST II - TRAIN TEST #1



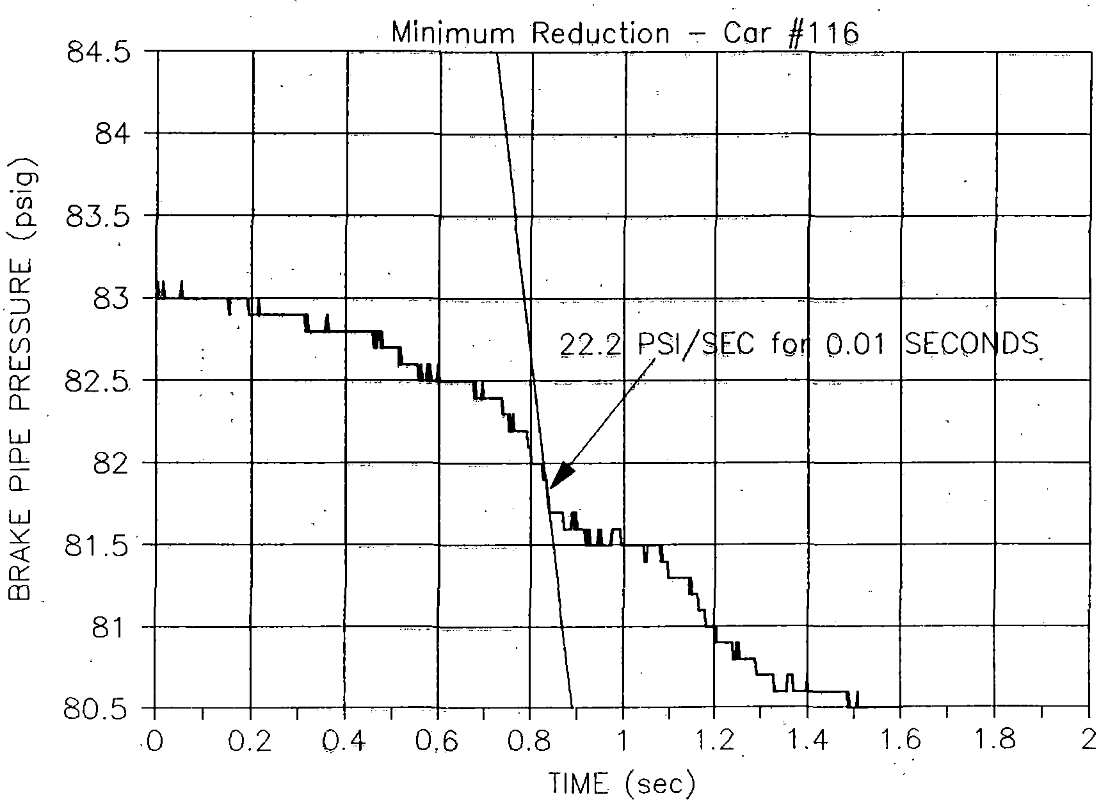
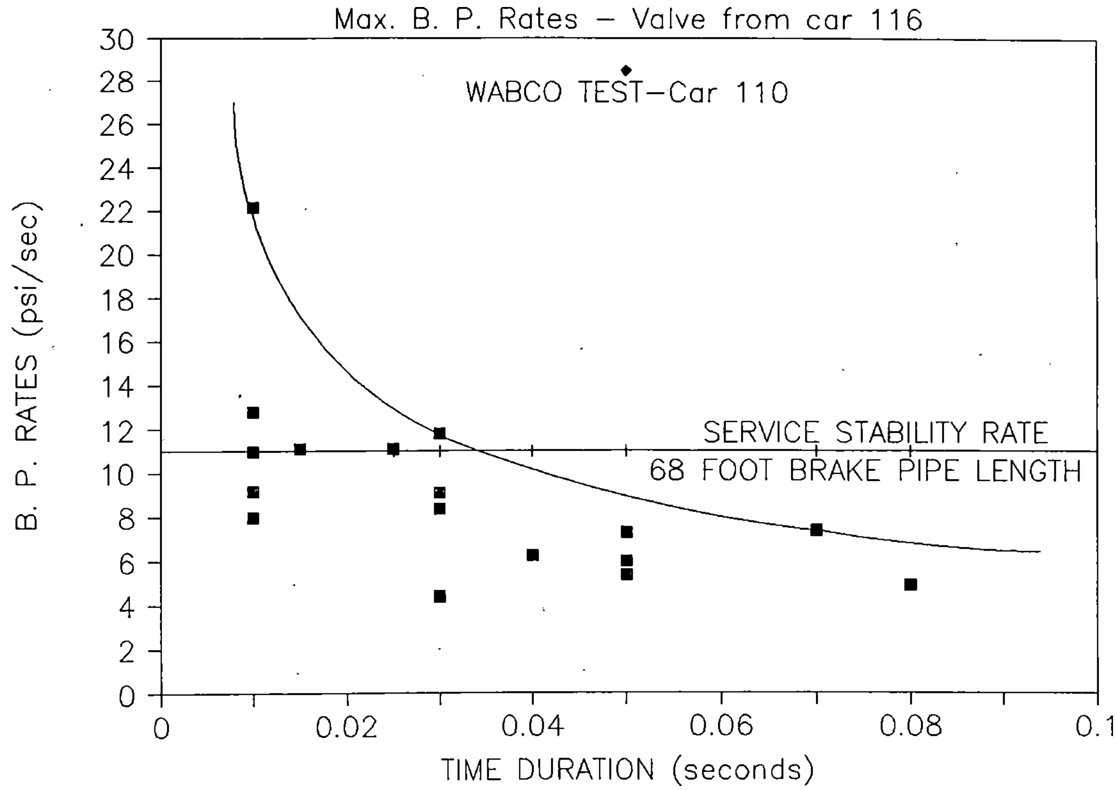


Exhibit 4.5

CP UDE TEST II - MAX. STABLE B.P. RATES



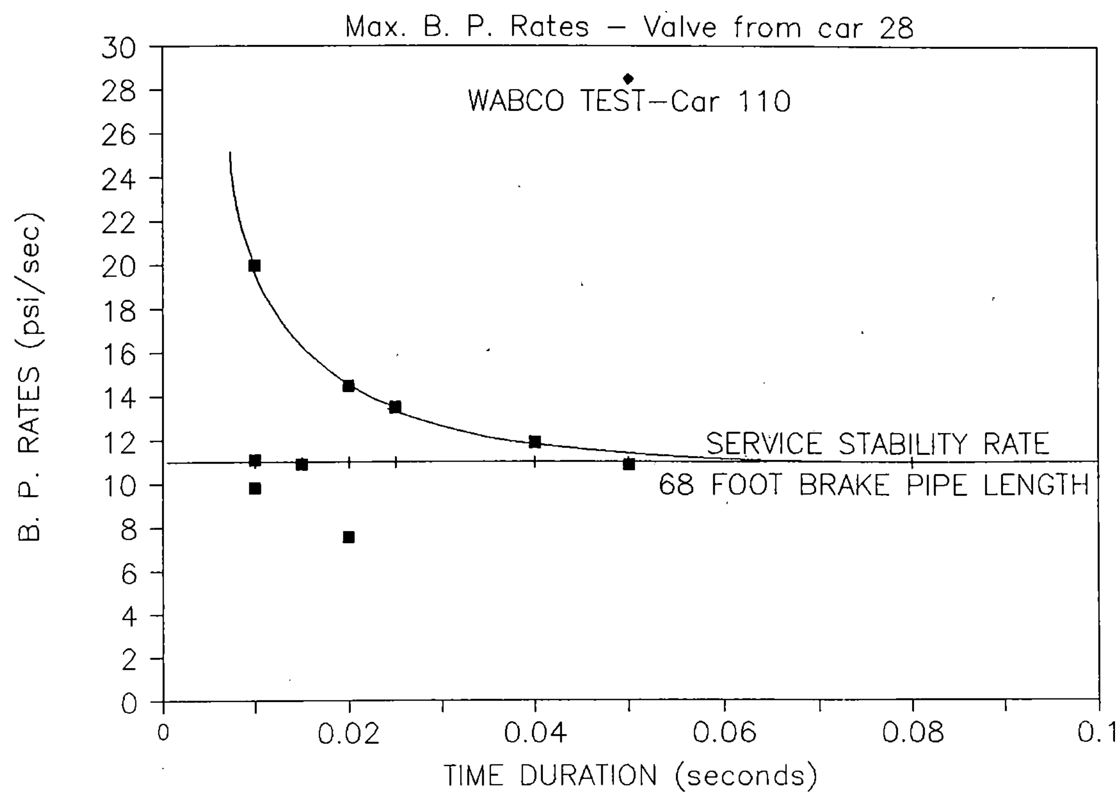


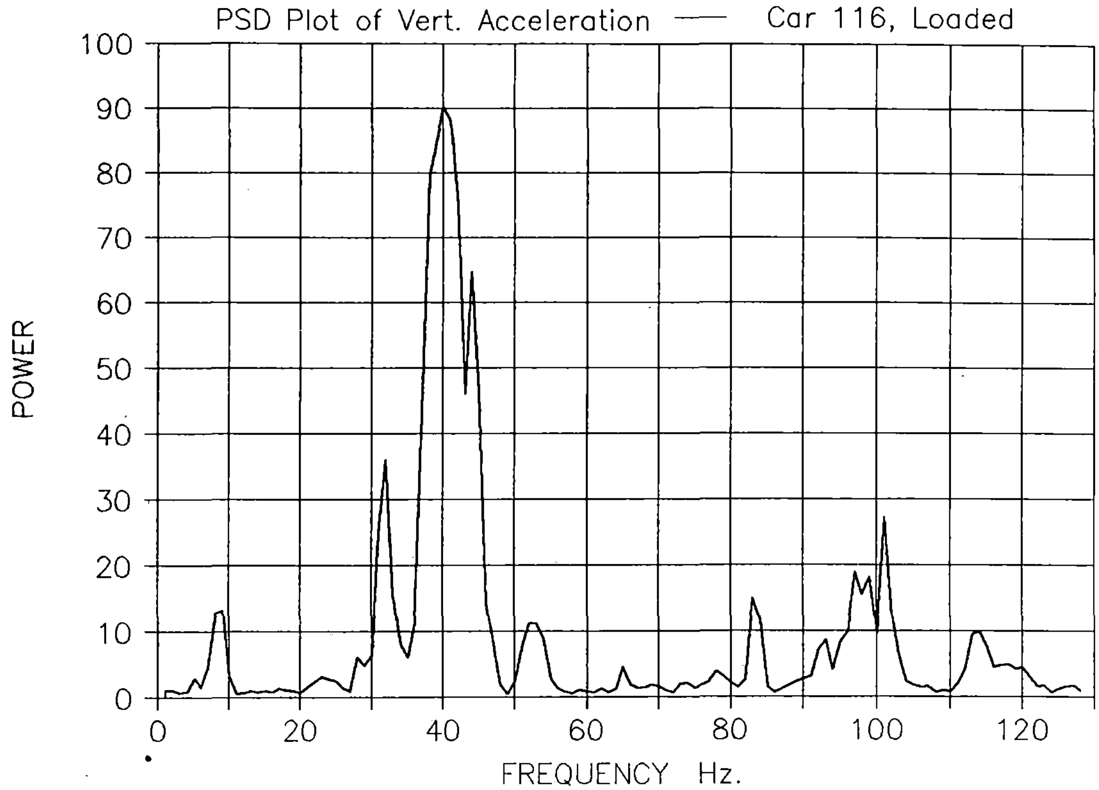
Exhibit 4.6

There appears to be a comfortable margin between the in service rates and the rate needed for the WABCO test of the valve from car #110. However, two factors must be considered. First, since the rate at a control valve as it initiated an emergency during the second train test was not recorded, rates higher than those measured may and probably do occur. Second, the WABCO tests were done on a stationary test rack, and were not subject to vibration. This raised a new question. Instead of vibration causing a higher coefficient of friction at the emergency slide valve (the "stiction" theory), perhaps vibration causes a lower coefficient of friction, thereby reducing the damping of the emergency slide valve. This might allow the piston to over shoot to emergency position in response to high rates of short duration which it would otherwise ignore in a stationary test condition.

4.4.3 VIBRATION

Vibration data was taken on the three empty runs and one loaded run. The dominant frequencies are about 40 Hz., and accelerations are between .5 and 1.0 G, with occasional higher spikes of about 2 G. There was very little difference between data taken under loaded and empty conditions, and car location had no significant effect. Exhibit 4.7 shows some typical PSD plots of the data collected. This data was used in further vibration testing at the AAR Technical Center.

CP UDE TEST II



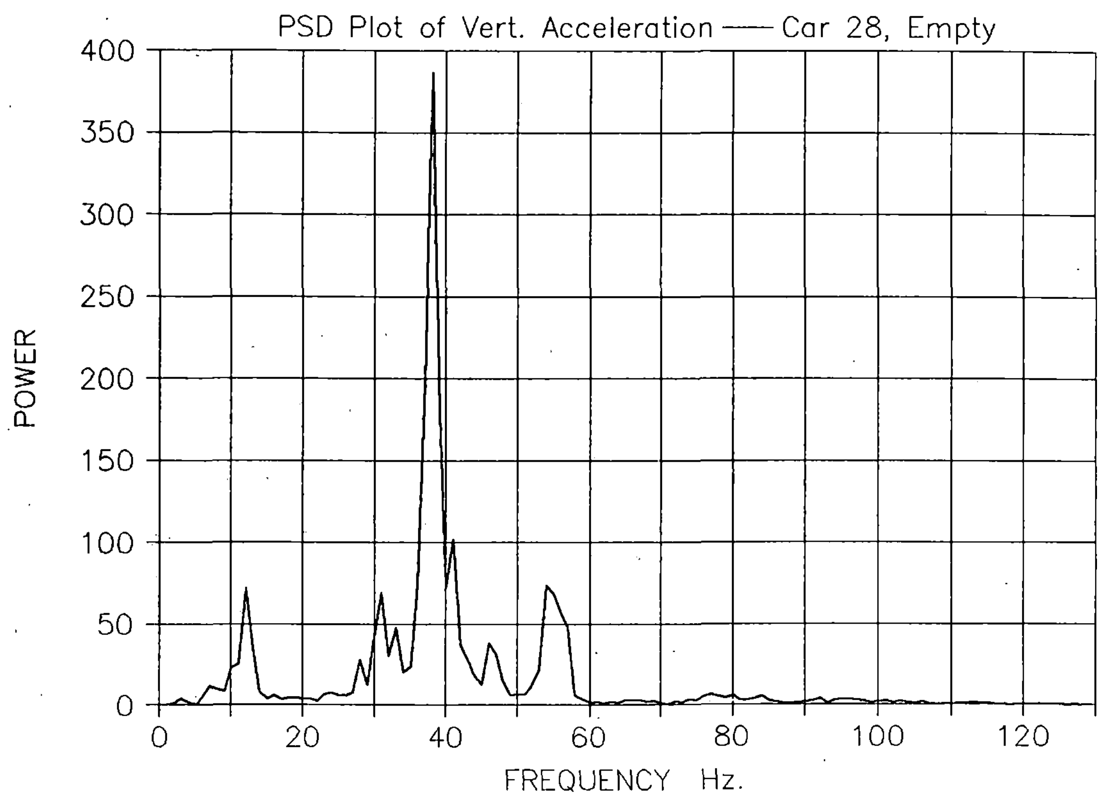


Exhibit 4.7

5.0 STATIONARY RIP TRACK TESTS

5.1 TEST PROCEDURE

After the conclusion was reached that the service stability portion of the AAR Single Car Code of Tests may be inadequate for higher brake pipe volumes, field tests were conducted on Illinois Central Gulf (ICG) and Chicago & North Western (C&NW) repair tracks and at the AAR Chicago Technical Center (CTC) to determine how the service stability test should be changed. The tests determined the brake pipe reduction rates in handle position #6 and the maximum stable reduction rates on cars with different brake pipe lengths. All of the data was recorded on a Data-Logger at a sample rate of 500 Hz.

5.2 RESULTS

Exhibit 5.1 lists the service stability rates in handle position #6 and the maximum stable rates recorded on cars with brake pipe lengths ranging from 36 feet to 130 feet. The service stability rates were achieved in accordance with the present service stability test. Also listed is the 14.3 psi/sec maximum no/go rate, which has been the industry standard for the AB test rack. In the case of the cars equipped with a #8 vent valve, the vent valve was plugged before a service stability test was made on the control valve itself. The #8 vent valve requires a lower reduction rate over a longer time period to go to emergency than does a control valve. Thus the vent valve is not as susceptible to the steps and ramps of an in-service reduction as is the control valve, but will go into emergency in response to a more stringent service stability test.

Exhibit 5.1

B.P. Length (feet)	Valve Type	Service Stability Rate psi/sec	Maximum Stable Rate psi/sec
Industry standard			14.3
36	AB	12.74	17.86
49	AB	10.58	**
62	ABDW	7.94	12.05
101	ABD	5.33	8.48*
130	Z1AW	4.04	7.75*

*   #8 Vent valve plugged.
**   Not measured.

5.3 DISCUSSION

It should be noted that the severity of the service stability test reduces with increasing lengths of brake pipe. The present service stability test appears adequate for cars with up to 75 feet of brake pipe. However, there is a real possibility that some of the UDEs attributed to long cars are due to the fact that, with the present service stability test, a car with an overly sensitive valve will pass the test every time, yet will kick when in a train.

A surprising result of the tests to date shows that the maximum stable reduction rates during single car tests seem to increase with brake pipe length. This occurred even when the same control valve was moved from a short car to a longer car. While it is true that the longer cars have more brake pipe volume, it was felt that the maximum stable rate would remain relatively constant, and just require a larger orifice to achieve that rate with long cars.

There has been some question as to whether the single car test should be done at 70 psi or a more service representative pressure of 90 psi. The CTC has conducted single car tests at both pressures in the course of this study. There is little difference in the way a valve performs at either pressure. A sensitive valve at 70 psi remains sensitive at 90 psi. However, at the higher pressure leakage is easier to detect, and in some cases leakage occurs at 90 psi, but not at 70 psi. Thus a car may pass the present leakage test at 70 psi, yet leak badly at 90 psi from a location which was "tight" at the lower pressure.

As this report is being written, the AAR Brake Equipment Committee is working on an improved Single Car Test and an improved Repair Track Air Test. These proposed tests will include a service stability test at two reduction rates for brake pipe lengths under and over 75 feet, and will be made at 90 psi.

6.0 AAR CHICAGO TECHNICAL CENTER VIBRATION TESTS

A total of sixteen emergency portions were tested at the CTC to determine if a control valve would become more sensitive when subjected to in-service levels of vibration. The sources of the control valves are given in Exhibit 6.1.

The ATSF valves came from a 50 car revenue TOFC train which had experienced a high number of UDEs. The ATSF replaced all 50 emergency portions, and only one more UDE occurred on the train. Some of the emergency portions were disassembled by the Santa Fe with no conclusive results. The remaining intact valves were sent to the CTC. One or more of these valves may have been a kicker.

6.1 TEST PROCEDURE

The valves were mounted on an aluminum pipe bracket which was in turn bolted to a vibration table. The pipe bracket was connected to a single car test rack so that the test valve could be pressurized and operated while under vibration. The resulting brake pipe length of the test set up was 22 feet. The tests consisted of determining the maximum stable brake pipe reduction rate using chokes in the 3/8 inch cock of the single car test device which was connected to the single car test rack. The valves were initially tested statically at 70 and 90 psi to establish a baseline. Then the valves were pressurized to 90 psi and vibrated at 40 Hz. and 8 Hz., based on the vibration data taken on the CP. The valves were allowed to vibrate for periods of time ranging from one hour to 18 hours before brake applications were made.

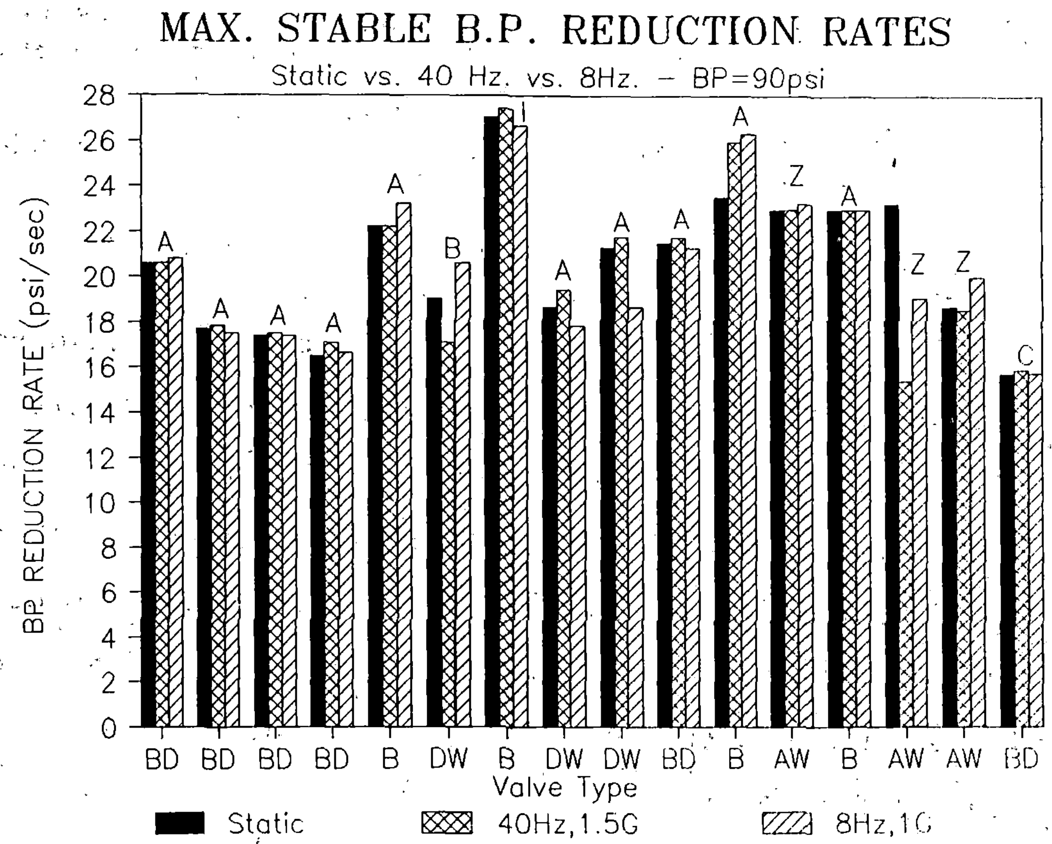
Exhibit 6.1

# OF VALVES	TYPE	SOURCE
1	ABD	Confirmed kickers from CP test train of May, 1985.
1	ABDW	CSX, failed single car test.
3	AB	ATSF test train of 1985-86.
5	ABD	ATSF test train of 1985-86.
2	ABDW	ATSF test train of 1985-86.
1	AB	ICG rip track tests
1	Z1AW	New CTC test valve.
2	Z1AW	UTTX110014, Arc 5 intermodal car.

6.2 RESULTS

Exhibit 6.2 is a graph of the results. It should be noted that the most sensitive valve under static and vibratory conditions was the confirmed kicker from the first CP test. This was the only confirmed kicker tested in this manner. There was no significant effect on the operating characteristics of the test valves. Some became less sensitive, some became more sensitive, and some showed little or no change. Other frequencies from 6 to 65 Hz. were tried on a few valves with no significant results.

From these tests, it appears that vibration is not as much a factor in UDEs as was previously thought.



SOURCES - A-ATSF B-CSX I-ICG Z-Z1AW C-CP
VALVE TYPES - BD-ABD DW-ABDW B-AB AW-Z1AW

Maximum stable BP reduction rates for various control valves at 0, 8 and 40 Hz.

Exhibit 6.2

7.0 SANTA FE TRAIN TESTS

Because the CP unit coal train was not a typical UDE prone train, it became necessary to identify kickers from a typical TOFC train. This was done with the cooperation of the Santa Fe in July of 1986. The test consisted of a round trip between Chicago and Los Angeles on a revenue 50 car TOFC train. The goals of this test were to;

1. Identify one or more kickers using modified detector hoses. These hoses were 22 inches long, with a nipple at one end, and a glad hand and ribbon at the other end. The standard detector hoses used on the previous CP tests allowed the hose couplings to hang too low.
2. Record brake pipe pressure at various points in the train during brake applications. To do this we now had three Data-Loggers which could be used simultaneously at three locations. We also had a NYAB supplied recorder which was used to continuously monitor the brake pipe pressure on the last TOFC car in the train.
3. Record brake pipe pressure on a valve as it kicks.
4. Measure temperature and humidity inside the brake pipe during the entire trip.
5. Measure vibration at the emergency portion of the control valve to see if it differed significantly from those levels measured on the CP coal cars.
6. If possible, note the effect of air dryers on the incidence of UDEs.

7.1 WESTBOUND TEST TRAIN

The westbound portion of the test consisted of a 54 car loaded TOFC train. The 20th car was the Santa Fe research car, and the 51st, 52nd, and 53rd cars were sleeping and dining cars for the test crew. The locomotives were not equipped with air dryers.

The 54th or last car was a TOFC flat from a Southern Pacific (SP) list of probable kickers. The SP generated this list by entering the consist of any train which experienced one or more UDEs into a computer. These consists were compared by the computer, and when a single car showed up more than 5 times it was put on the list. The particular car on the test train was previously in nine trains which had experienced UDEs.

There were 26 AB, 21 ABD, and 3 ABDW control valves on the fifty TOFC flats, and all had A1 reduction relay valves. The test car had an AB valve with no A1 or #8 valves, and the remaining three passenger cars had D22 equipment with no A1 or #8 valves.

The train experienced one kicker at Winslow, Ar. It occurred on the last TOFC car in the train, which was the car from the SP kicker list and which was monitored by the NYAB recorder. Unfortunately, The NYAB data on this valve was inconclusive. The UDE occurred after the train had slowed to about ten mph using dynamic brakes. A minimum application was made to bring the train to a complete stop, and this triggered the UDE.

7.2 EASTBOUND TEST TRAIN

The eastbound consist was an entirely different train with the exception of the car which had kicked and the four passenger cars. The train consisted of 52 loaded TOFC flats plus the research car and three passenger cars. The locomotives now had air dryers. The first car in the train was the car which had kicked during the westbound trip, and a Data-Logger was placed on this car for the entire trip back to Chicago. The last two TOFC flats were from the SP kicker list, and a Data-Logger and the NYAB recorder were used to monitor the last TOFC car. The last four cars in the train were the research car and the three passenger cars in that order. The valve types on the TOFC cars were 24 AB, 21 ABD, and 7 ABDW.

On the eastbound trip, six UDEs occurred. Two UDEs occurred on the 8th car, one UDE occurred on the 44th car, two occurred on the 47th car and one occurred on an unknown car which was not identified due to a premature release of the air brakes before the train could be inspected. The first car, which had kicked on the westbound trip, did not kick. Nor did the two cars at the rear of the train from the SP kicker list cause any UDEs. The Data-Logger was moved to the 44th car after it had kicked twice, after which it never kicked again. But car 47 did, so a brake pipe reduction on a UDE initiating valve has still not been recorded. The slack action was much more severe on the eastbound leg of the trip.

At this point, the conclusion could be made that based on this test dryers are of no use in preventing UDEs. This conclusion is not valid since nearly all of the variables in the test were changed in Los Angeles. There is a possibility that the westbound trip may have had no UDEs with dry air, and the eastbound trip may have had more with wet air. Since we were unable to run a back-to-back comparison using the same consist over the same terrain, the case for dryers is still open. However, since the last CP train test, the CP now uses dryer equipped locomotives in their coal train service, and the seasonal increases in UDEs no longer occur.

Exhibit 7.1 shows some plots of minimum applications on the 52nd car of the eastbound consist. As on the CP tests, there were no two minimum service reductions which were alike. Note the 1 psi pressure reduction in the plot at the top of Exhibit 7.1, and the subsequent 1/2 psi rise. The maximum reduction rates recorded during the Santa Fe test were not as high as on the CP tests, yet the same sort of pressure fluctuations were present, and they were more extreme on the eastbound trip with its heavier slack action.

7.3 POST TEST TESTING

All four kickers were sent to the CTC. When the cars were single car tested at 70 psi and at 90 psi, none failed the service stability portion of the test. When the maximum stable reduction rates were established for the cars, none appeared to be sensitive when compared with long cars tested previously, and none of the control valves or vent valves appeared sensitive.

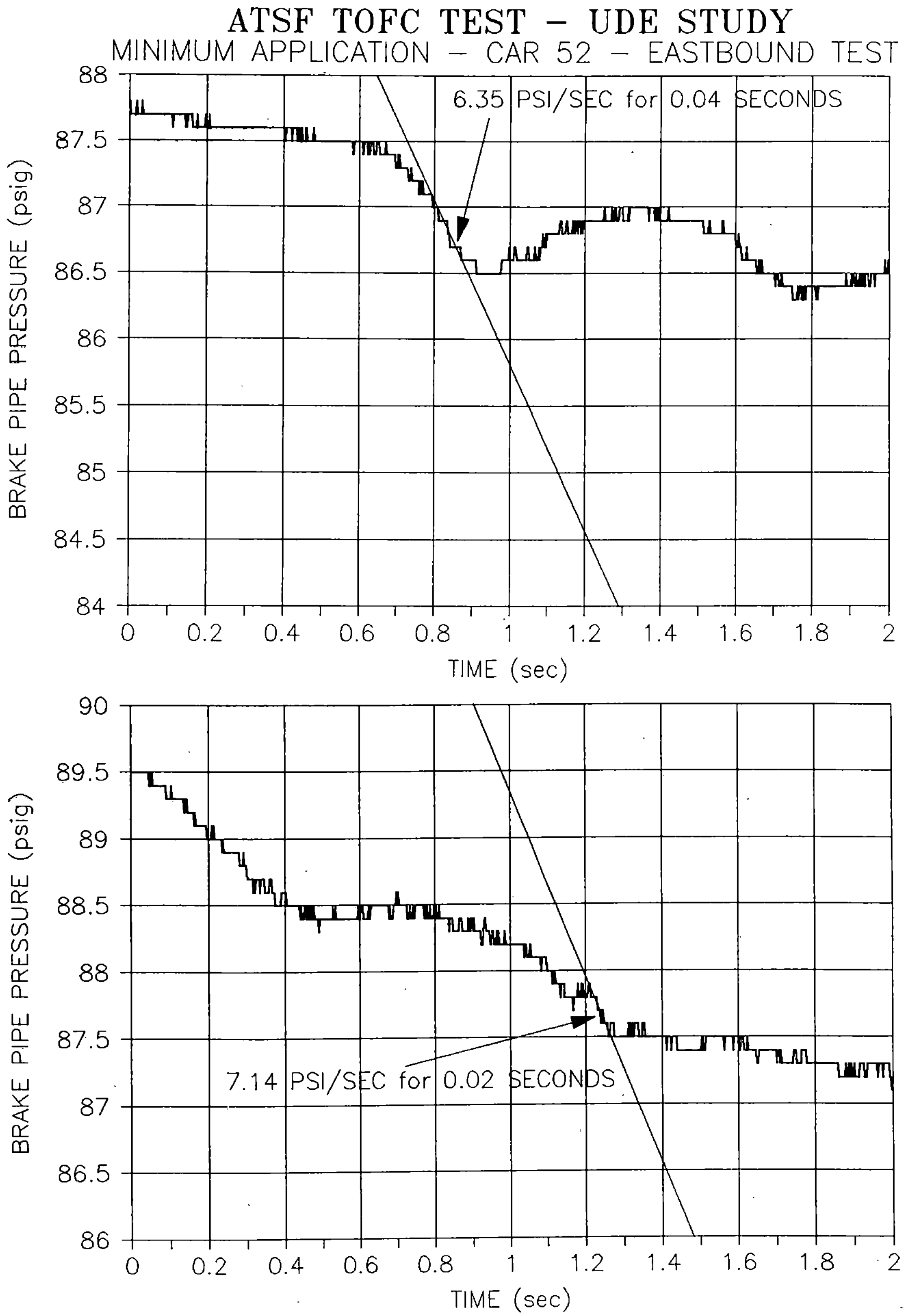

ATSF TOFC TEST - UDE STUDY
MINIMUM APPLICATION - CAR 52 - EASTBOUND TEST
6.35 PSI/SEC for 0.04 SECONDS
BRAKE PIPE PRESSURE (psig)
TIME (sec)
7.14 PSI/SEC for 0.02 SECONDS
BRAKE PIPE PRESSURE (psig)
TIME (sec)

Exhibit 7.1

All four valves were removed and tested on an AB test rack at WABCO's Chicago air room. None of these valves failed any UDE related portion of the AB rack test.

In addition to the four kickers at the CTC, seventeen cars from the eastbound consist were extensively tested at ATSF's Corwith Yard in Chicago. Of the total of twenty one cars tested, seven required cleaning, and ten of the twenty one cars had excessive leakage.

None of these cars would have failed any portion of the present repair track air test. In addition, none of these cars have failed the service stability portion of the single car code of tests. Another interesting fact which has emerged is that the cars which were located immediately behind each eastbound kicker had excessive leakage. In addition, preliminary inspection of the locomotive data tapes has indicated that for six of the seven UDEs the slack was either bunched or running in.

Because of the heavy slack action on the eastbound trip and the high number of UDEs, it was felt that slack action, through some unknown mechanism, might have caused the pressure fluctuations seen on the CP and Santa Fe tests. To check this theory, the four ATSF "kickers" were coupled together at the CTC and instrumented with a brake pipe pressure transducer on each car. These transducers were connected to one data acquisition system in order to see if any pressure pulses could be seen to travel the length of the four cars. The cars were initially parked with the slack stretched, then a locomotive was used to rapidly close the slack with and without minimum brake applications. Exhibit 7.2 illustrates the results on a test with no brake application. A 0.1 psi pressure fluctuation was generated as the slack closed on each car, which seemed to confirm that slack action does indeed effect brake pipe pressure. What remained to be seen was how significant this effect could be, and what was the exact mechanism involved.

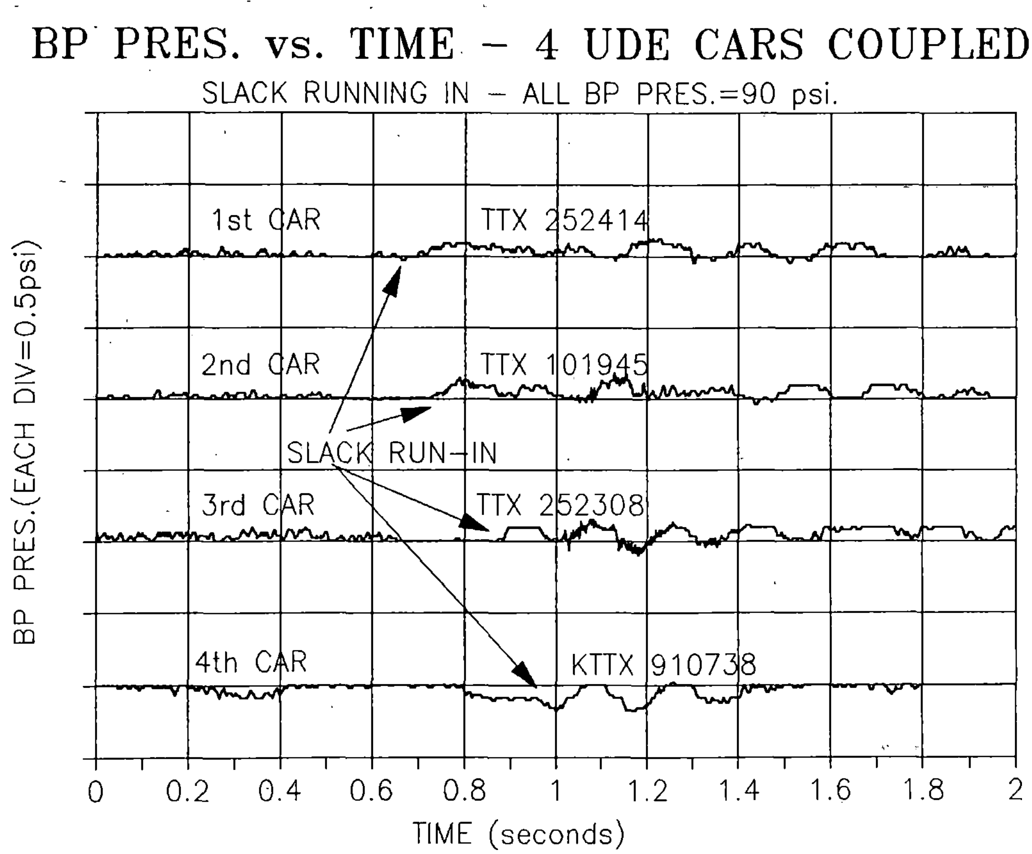


Exhibit 7.2

7.4 SANTA FE TEST CONCLUSIONS

1. The service stability portion of the single car code of tests is not a stringent performance test for the control valve on a long car.

2. The "trigger" mechanism which appears to cause most UDEs is a sharp pressure reduction lasting for a very short period of time, usually occurring during quick service activity of a service reduction.

3. A "kicker" valve is not necessarily defective, and may be reacting as designed in response to a sharp pressure reduction.

4. A likely cause of sharp brake pipe pressure reductions is harsh slack action. Testing to determine the effect of slack action alone on brake pipe pressure would be necessary.

5. Testing would be necessary to determine if a control valve would indeed respond to a sharp short duration pressure reduction by going into emergency.

6. Moisture in the air brake system may increase the sensitivity of a control valve, but this by itself will not cause a UDE.

8.0 CHICAGO & NORTH WESTERN TESTS

8.1 TEST PROCEDURE

Tests were run on the Chicago and North Western in July of 1987 to determine if the motion of the train caused brake pipe pressure fluctuations through slack action, vibration, leakage, or any combination of these factors. Four different types of trains were used between Chicago and Clinton, Iowa. The first was a 34 car westbound mixed manifest freight with seven long cars (over 75 feet of brake pipe). This train was later filled out with 21 long cars to total 55 cars (28 long cars). The second train was an eastbound double stack train with 30 5-unit articulated cars. The third train was a 50 car westbound containing auto rack and TOFC cars all of which were 85 to 89 feet long. The last train was an eastbound 113 car manifest freight with a good mix of car types, only 12 of which were long cars.

The brake pipe pressure recordings were made using two Data-Loggers recording at 500 scans per second. The Data-Loggers were programmed to constantly scan brake pipe pressure and keep the previous twelve seconds of data continually stored in a buffer. When slack action was felt in the caboose, the Data-Logger was manually triggered to record the previous twelve seconds of data on tape. The pressure transducers and Data-Loggers were located in the dirt collector bowl of a test caboose, which was the last car in each test train.

8.2 DISCUSSION OF C&NW TEST RESULTS

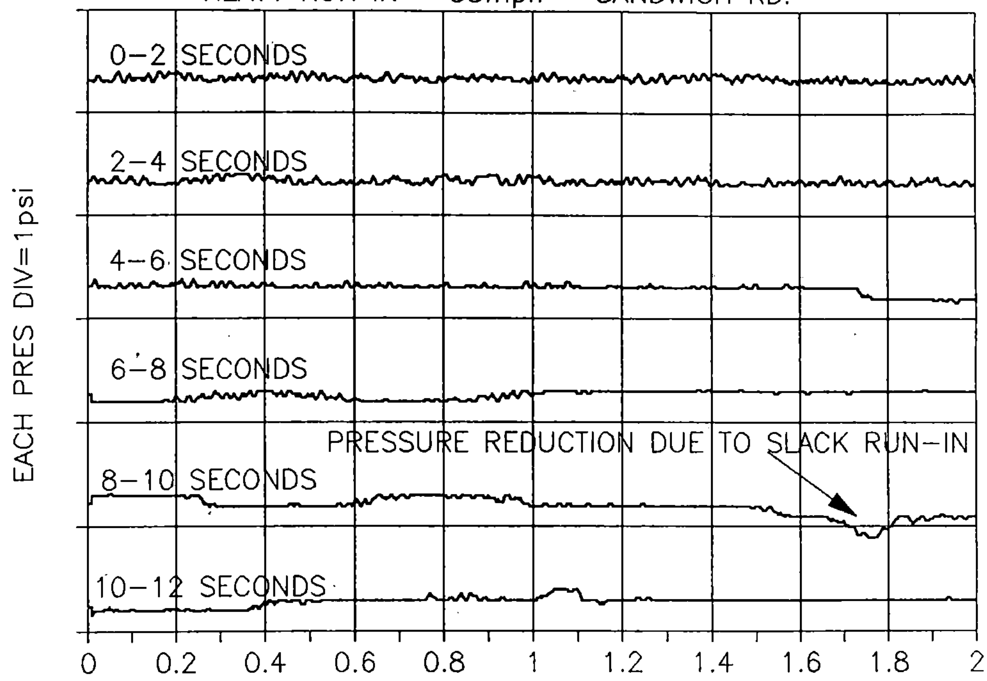
The analysis of the data strongly suggested that the mass of the air in the brake pipe reacts to the sudden accelerations imposed by severe slack action. Twenty-two run-ins and fourteen run-outs were recorded. With the exception of 5 of the run-ins, all of the slack run-ins produced a general pressure reduction of up to 0.4 psi at the rear of the train, due to the air continuing to run forward in the brake pipe as the rear of the train suddenly decelerated. Conversely, the run-outs produced a pressure increase of up to 0.45 psi in the test caboose due to the air mass wanting to remain at a slower initial speed and running to the rear of the train. These pressure changes were not sudden events, but rather happened over a one to four second time span. The intensity of these pressure changes seemed to vary in proportion to the severity of the slack action.

Exhibit 8.1 shows two plots of brake pipe pressure recorded during a slack run-in and a slack run-out. The vertical axis of these graphs are un-numbered and each major division is one psi. The initial brake pipe pressure is noted on the vertical axis. The top line is the first two seconds of data, with the second two seconds of data plotted below that, and the third two seconds below that, and so forth for a total of twelve seconds of constant pressure data without any brake applications. The slack event which caused the recording to be made generally occurred 1.5 to 2.5 seconds prior to the end of the record.

A second result of this test was the hypothesis that brake pipe pressure fluctuations are probably the result of volume changes caused by hose bending during changing slack conditions. These fluctuations in combination with the brake pipe air mass flow might have created the short duration high reduction rates referred to in the previous CP and ATSF tests. Exhibit 8.2 is a plot of the brake pipe pressure recorded on the last car of the double stack train during a slight run-in due to a dynamic brake application. Note that in addition to the general pressure reduction of 0.15 psi, there are periodic pressure disturbances occurring every 0.6 to 0.8 seconds. The double stack train had no severe slack action, and all of the run-ins were gentle (there were no significant run-outs). The train was 8400 feet long, yet had a gradient of about 0.5 psi, which makes leakage an unlikely cause. The train behaved like a tight, conventional 30 car train, even though each car was about 250 feet long. Recordings of brake pipe pressure made while moving over diamonds and cross-overs showed that rough stretches of track had no effect on brake pipe pressure. Therefore, it appeared that the periodic fluctuations were due to hose bending between each car during the gradual run-in of one 250 foot car at a time. The period between fluctuations of 0.6 to 0.8 seconds indicates a run-in speed of about 300 to 400 feet per second, which seems reasonable. The shape and nature of the pressure fluctuations on the other three types of trains were very similar to those recorded on the stack train, but they were slightly larger, there were more of them, and they were not periodic. Therefore, it appeared that hose bending and deformation during changing slack conditions could have been instrumental in the formation of rapid short duration pressure reductions.

C&NW UDE TEST, 53 CAR FRT(28 LONG CARS)

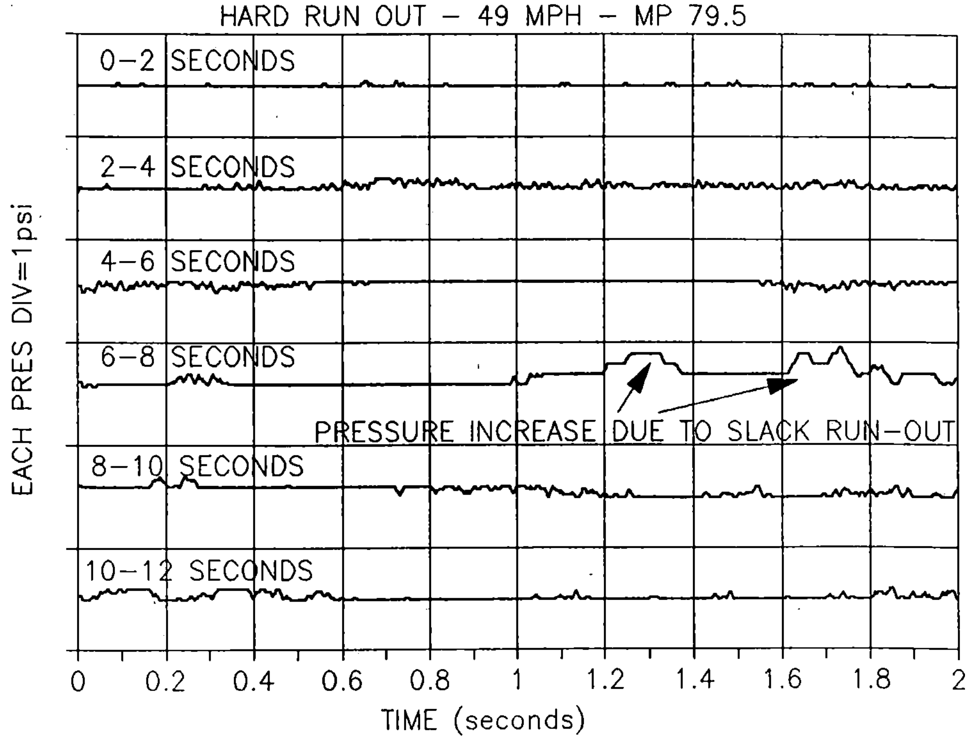
HEAVY RUN IN – 38mph – SANDWICH RD.



INITIAL BP PRESSURE = 72.3 psi

C&NW UDE TEST, 113 CAR FRT (12 LONGS)

HARD RUN OUT – 49 MPH – MP 79.5



INITIAL BP PRESSURE = 87 psi

Exhibit 8.1

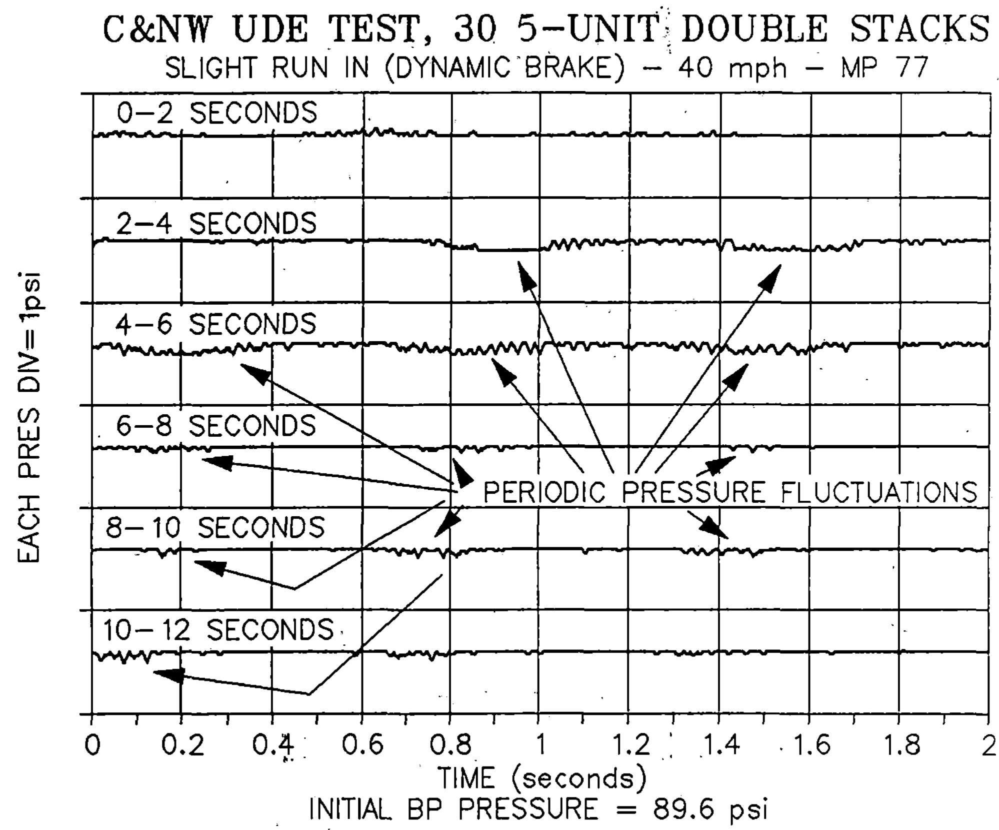

C&NW UDE TEST, 30 5-UNIT DOUBLE STACKS
SLIGHT RUN IN (DYNAMIC BRAKE) - 40 mph - MP 77
0-2 SECONDS
2-4 SECONDS
4-6 SECONDS
6-8 SECONDS
8-10 SECONDS
10-12 SECONDS
PERIODIC PRESSURE FLUCTUATIONS
EACH PRES DIV= 1psi
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
TIME (seconds)
INITIAL BP PRESSURE = 89.6 psi

Exhibit 8.2

9.0 HOSE FLEXING TEST

9.1 TEST PROCEDURE

The effects of hose flexing were simulated by recording brake pipe pressure on a single car test rack with 52 feet of actual brake pipe (no simulated volumes) charged to 85 psi. A pressure transducer was mounted in the dirt collector bowl approximately 25 feet from the hoses. Recordings were made at 500 scans per second when the glad hand was impacted by a hammer, and when the glad hand was simply moved through a 6 to 8 inch arc by hand without kinking the hose. Exhibit 9.1 shows the result. Note on the middle pressure trace that a very fast spike occurs at the impact of the hammer, and 0.1 psi fluctuations occur after the impact as the hose swung back and forth. On the bottom pressure trace, where the glad hand was moved by hand, there are regular 0.1 psi fluctuations.

These results seemed to confirm that hose bending can contribute to rapid pressure fluctuations, although they would appear to be of low magnitude. However, when these rapid low magnitude fluctuations are combined with the effects of inertial air flow due to slack action and quick service activity, they could have a detrimental effect.

EFFECTS of FLEXING TRAIN LINE HOSE

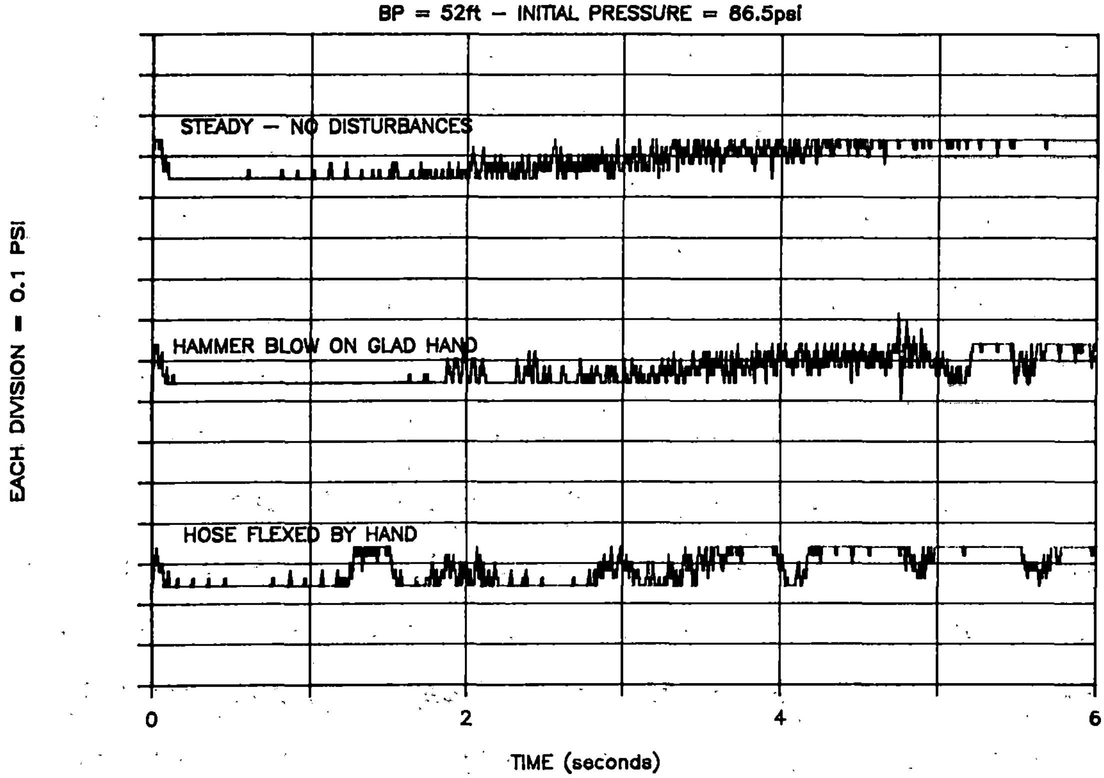


Exhibit 9.1

10.0 EFFECTS OF BRAKE PIPE AIR TEMPERATURE AND HUMIDITY

10.1 TEST PROCEDURE

Tests to determine temperature and humidity effects were done by measuring the changes in valve sensitivity when the control valve was subjected to "wet" and dried air in an environmental chamber set at 38 degrees F. The outside air fed to the control valve was 80 to 90 degree humid air near the saturation point, and when the air reached the control valve it was saturated at 38 degrees. Comparison tests were made with and without a two stage locomotive dryer. The humidity of the brake pipe air with the dryer was about 40%. The control valve sensitivity was determined by varying the size of the choke in the 3/8" diameter cock of a single car test device. The temperature and humidity of the brake pipe air was measured inside the dirt collector bowl. A thermocouple was installed in the airstream of the quick action chamber breather choke to determine if freezing condensation might be restricting this choke, which would cause the valve to go into emergency. A non-contacting displacement transducer was used to measure the movement of the emergency piston. The air temperature and humidity inside the control valve was allowed to stabilize prior to each test.

10.2 TEST RESULTS

The data did not show any change in sensitivity due to brake pipe humidity. The thermocouple data did show that the airstream out of the quick action chamber breather choke dropped to about 28 degrees F, but there was no evidence of any increased restriction of the QAC breather choke due to freezing. The emergency piston movement was not noticeably different in wet versus dry conditions. However, it appears that the seasonal increases in the number of UDEs in Canadian Pacific coal train service has dropped significantly with the increased use of dryer equipped locomotives in that service and with improved maintainance procedures. So while there is some indication that weather conditions can effect control valve sensitivity, it remains very difficult to prove.

11.0 UNIVERSITY of NEW HAMPSHIRE BRAKE SYSTEM MODEL

11.1 BACKGROUND

The University of New Hampshire (UNH) had been developing a computer model of the ABDW control valve and the brake pipe for NYAB. The model incorporated the dynamics of piston movement and the variable opening and closing of ports, which had never been done before. With the generous cooperation of NYAB, the AAR contracted with UNH to develop a "generic" control valve and pipe model which included the effects of acceleration and slack action. The UNH/AAR brake pipe model has now advanced to the point where the effects of slack action can be simulated. Preliminary runs of the model have indicated that a 1.5 G slack run-in of 0.12 second duration on the last 50 cars of a 100 car train of 50 foot cars is sufficient to cause an UNINTENDED MINIMUM SERVICE BRAKE APPLICATION on the last 80 cars. Using the same simulation, a 1.6 G run-in of 0.12 second duration on the last fifty cars caused a UDE, without a service brake application being made. These results, although they are preliminary and as yet unsupported by field data, do tend to support the hypotheses concerning air mass flow during periods of changing slack conditions. A more detailed description of the model by Prof. D. E. Limbert of the University of New Hampshire is presented in Appendix A.

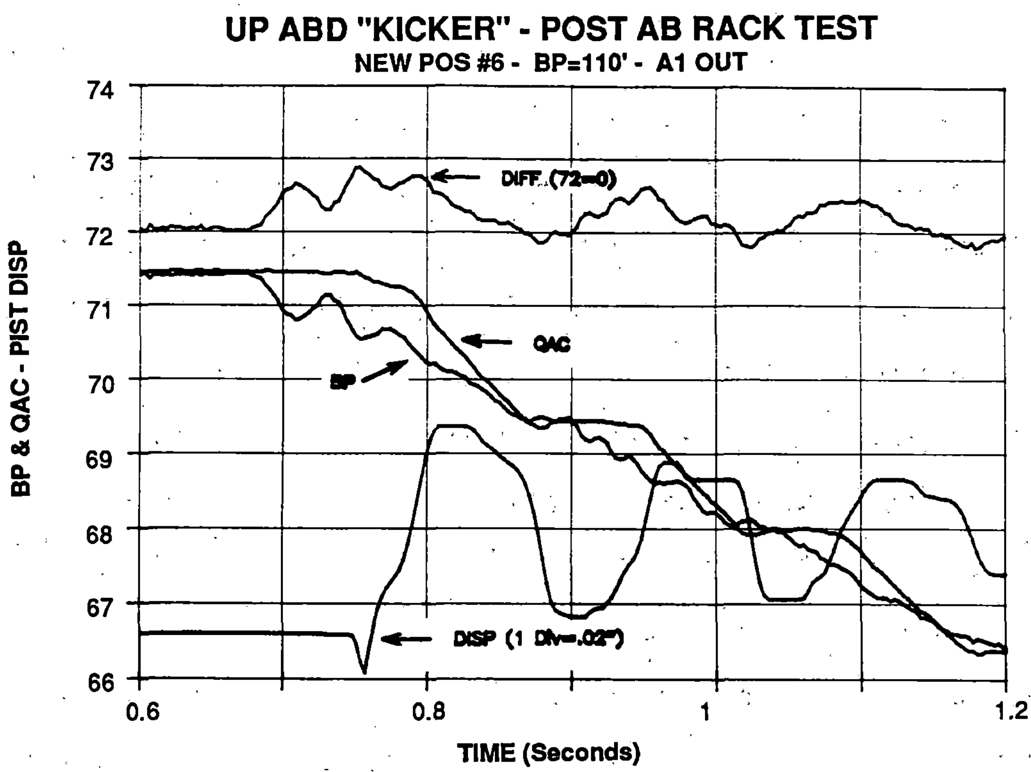
12.0 <u>INVESTIGATION OF TWO CONFIRMED "KICKERS"</u>

At this point in the UDE study, 16 control valves had been positively identified as "kickers", yet they had all passed the standard AAR AB Rack Tests. Since that time, the AAR received two ABD control valves from the Santa Fe and Union Pacific which consistently failed the service stability portion of the single car tests administered by their repair track personnel and by the AAR at the Chicago Technical Center (CTC). The maximum stable reduction rates of these valves recorded at CTC were obtained by using various sizes of chokes in the 3/8" cock of a single car test device. The test device was connected to a single car test rack set up with 110 feet of brake pipe and the A1 reduction relay valve was cut out. The Union Pacific valve required a #28 drill (0.1405 inch diameter) choke to produce an emergency, which is only sightly smaller than the present position #5 port size of a #26 drill (0.147 inch diameter). The Santa Fe valve required a #36 drill choke (0.1065 inch diameter), so it was more unstable than the Union Pacific valve. It was decided to take these valves to the WABCO air room in Chicago for AB rack tests and careful disassembly to try to determine why these valves failed.

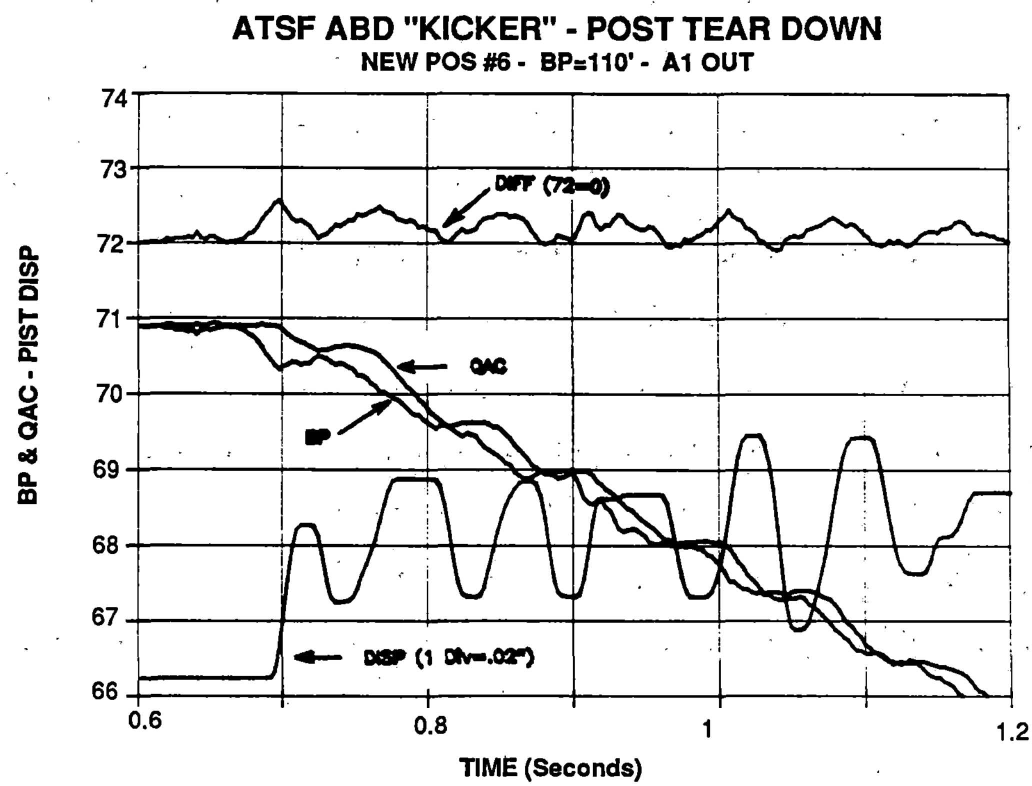
The Union Pacific valve, for reasons unknown, passed the AB rack test, and it has passed all subsequent single car tests at CTC, done again with 110 feet of brake pipe and the A1 cut out. The Union Pacific valve now required a #2 drill (0.221 inch diameter) choke to achieve a maximum stable rate, which is about average for control valves on 110 foot of brake pipe. No concrete reason for the valve's apparent sudden change in sensitivity has been found. However, the most likely cause of the initial valve failure is the failure of the spill-over check valve to seat properly. This would cause a direct communication between the emergency reservoir and the quick action chamber, thereby insuring a large pressure differential across the emergency piston during a service application, forcing the emergency piston to emergency position. This is supported by the fact that during the initial single car tests the valve went to emergency almost immediately after the service stability reduction began. It is possible that some foreign material was on the spill-over check valve seat, and only became dislodged when the valve was moved to the WABCO air room. This control valve was not torn down. Only the emergency portion top cover was removed and replaced with a cover which mounted a displacement transducer after the WABCO AB rack tests.

The Santa Fe valve also showed a sudden change in sensitivity during the AB rack tests, again for unknown reasons. However, even though this valve will now pass the AB rack test and the service stability test, it is by far the most sensitive "good" valve we have found. Subsequent testing showed the maximum stable rate choke for 110 feet of brake pipe was now a #16 drill (0.177 inch diameter). The change in sensitivity of both valves was similar. The Union Pacific valve went from just barely failing the test to average, while the Santa Fe valve went from failing by a wide margin to just passing. Perhaps the Santa Fe valve also had a problem with the spill-over check valve. The Santa Fe valve was partially torn down and evidence of some dirt was found when the passages were blown out. The QAC breather choke was checked for obstruction and proper size and no exceptions were taken. The emergency piston diaphragm was found to be crimped for about 15 degrees of its circumference, but it was a consensus of opinion that this had no effect, and this was borne out in further tests.

Both valves were then extensively re-tested at the CTC. Exhibit 12.1 shows the data plots from the tests on both the Union Pacific and the Santa Fe valves. The motion of the emergency slide valve on the Santa Fe control valve was faster and more extensive than the UP slide valve. Because of this, both emergency slide valves were inspected for wear. It was found that the Santa Fe slide valve showed wear in the area illustrated in Exhibit 12.2. Note that wear such as this would not result in slide valve leakage. However, since the primary seating force of the emergency slide valve is QAC pressure acting on the seating area, and since the seating area on this particular slide valve is reduced due to wear, the resulting friction between the valve and its seat is reduced. This allows the slide valve and the emergency piston to move sooner, farther, and faster for a given pressure differential. This would tend to make the control valve more sensitive, and explains why the piston movement of the Santa Fe valve is relatively un-damped



UP ABD "KICKER" - POST AB RACK TEST
NEW POS #6 - BP=110' - A1 OUT
BP & QAC - PIST DISP
TIME (Seconds)
DIFF (72=0)
QAC
BP
DISP (1 Div=.02")
74
73
72
71
70
69
68
67
66
0.6
0.8
1
1.2



ATSF ABD "KICKER" - POST TEAR DOWN
NEW POS #6 - BP=110' - A1 OUT
BP & QAC - PIST DISP
TIME (Seconds)
DIFF (72=0)
QAC
BP
DISP (1 Div=.02")
74
73
72
71
70
69
68
67
66
0.6
0.8
1
1.2

Exhibit 12.1

when compared to the Union Pacific valve.

So, to date the AAR had identified 18 confirmed kickers, 16 of which passed the service stability test, and two of which failed the service stability test. This points out the fact that while most UDEs are probably caused by train line pressure fluctuations, there is still the possibility of a bad control valve. Both the Union Pacific and the Santa Fe valves could have been found with a single car test or the old In-Date test, possibly before they failed in train service. HOWEVER, IT IS LIKELY THAT NEITHER VALVE WOULD HAVE FAILED THE PRESENT REPAIR TRACK AIR BRAKE TEST.

EMERGENCY SLIDE VALVE FROM ATSF "KICKER"

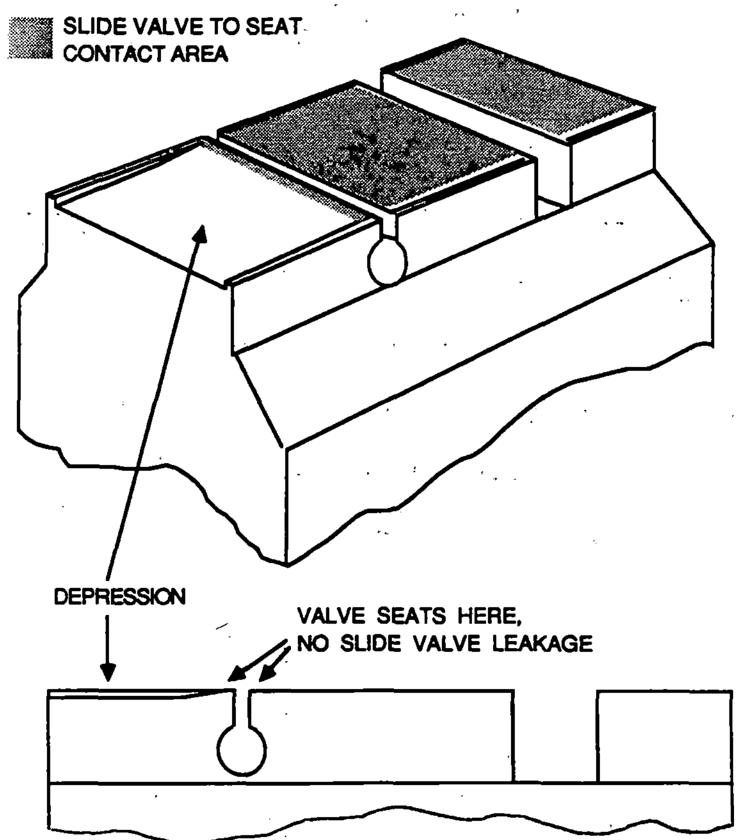


Exhibit 12.2

13.0 LABORATORY SIMULATIONS OF UNDESIRED EMERGENCIES

13.1 THEORY

It had been theorized previously that pressure fluctuations of about 35 to 40 psi/sec lasting for about 10 milliseconds should be sufficient to cause a good control valve to go into emergency. However, there has been some question as to whether a control valve could respond to pressure pulses as short as 10 milliseconds in duration. In an effort to answer this question, as well as gain some insight into the kind of pressure fluctuations we would look for during the upcoming Pueblo UDE train test, a laboratory test was designed to duplicate these short, rapid pressure reductions.

13.2 TEST PROCEDURE

The test consisted of connecting a single car test rack to an air spring. The air spring was expanded to its maximum travel of about 4.5 inches, and had an effective diameter of about 12 inches. The total brake pipe volume of the rack and air spring was about 1080 cubic inches, or about 70 feet of brake pipe. The air spring was placed in an MTS machine which upon a signal would allow the air spring to expand a controlled distance at a controlled speed. Brake pipe reductions of about 5 psi/sec. were made in order to simulate the type of quick service activity commonly seen at the rear of a train. The MTS machine was triggered to create a pulse when the brake pipe pressure dropped to 88 psi.

Instrumentation consisted of two differential pressure transducers reading brake pipe and quick action chamber pressures. These pressure transducers only measured from 90 to 75 psi, with much better resolution than the transducers used previously. A third pressure transducer was mounted in the vent valve diaphragm chamber in a manner which did not alter the very small volume of this chamber. The use of the vent valve transducer enabled us to very accurately determine when the exhaust port of the emergency slide valve opened and closed, and thus to determine when the emergency piston was in emergency position. In addition, we used a non contacting type of displacement transducer to measure the movement of the emergency piston. This data was collected by an HP computer, which was also used to trigger the MTS system. Exhibit 13.1 is a photo of the test set-up.

Exhibit 13.1

13.3 RESULTS

The volume change necessary to create the pressure fluctuations resulting in emergency applications was typically 7 cubic inches, or an increase of only 0.6% over the original brake pipe volume. The gain on the MTS response was turned down to the point that a ramp command to the MTS resulted in a haversine response. This was done to eliminate overshoot, and the resulting actual MTS head speed needed to produce an emergency was about 2.5 to 2.7 inches per second over a distance of less than 0.06 inches.

Two control valves were tested. The first was the previously mentioned very sensitive Santa Fe ABD kicker. Using this valve, the minimum reduction rate necessary to cause the emergency slide valve to move to emergency position and begin feeding pressure to the vent valve diaphragm was 38.5 psi/sec at a duration of .013 seconds (Exhibit 13.2). Note that there is a brake pipe pressure rebound after the initial rapid reduction. The rebound in this case possibly saved the control valve from going to emergency by pushing the emergency piston back into service position. This rebound was a constant problem throughout the tests, and resulted in somewhat higher reduction rates than predicted. It should be remembered that the train test data gathered on the CP and ATSF UDE train tests did not typically show this pressure rebound after a rapid reducing pressure fluctuation. A fluctuation rate of 45.5 psi/sec. for .011 seconds was required to produce an emergency application.

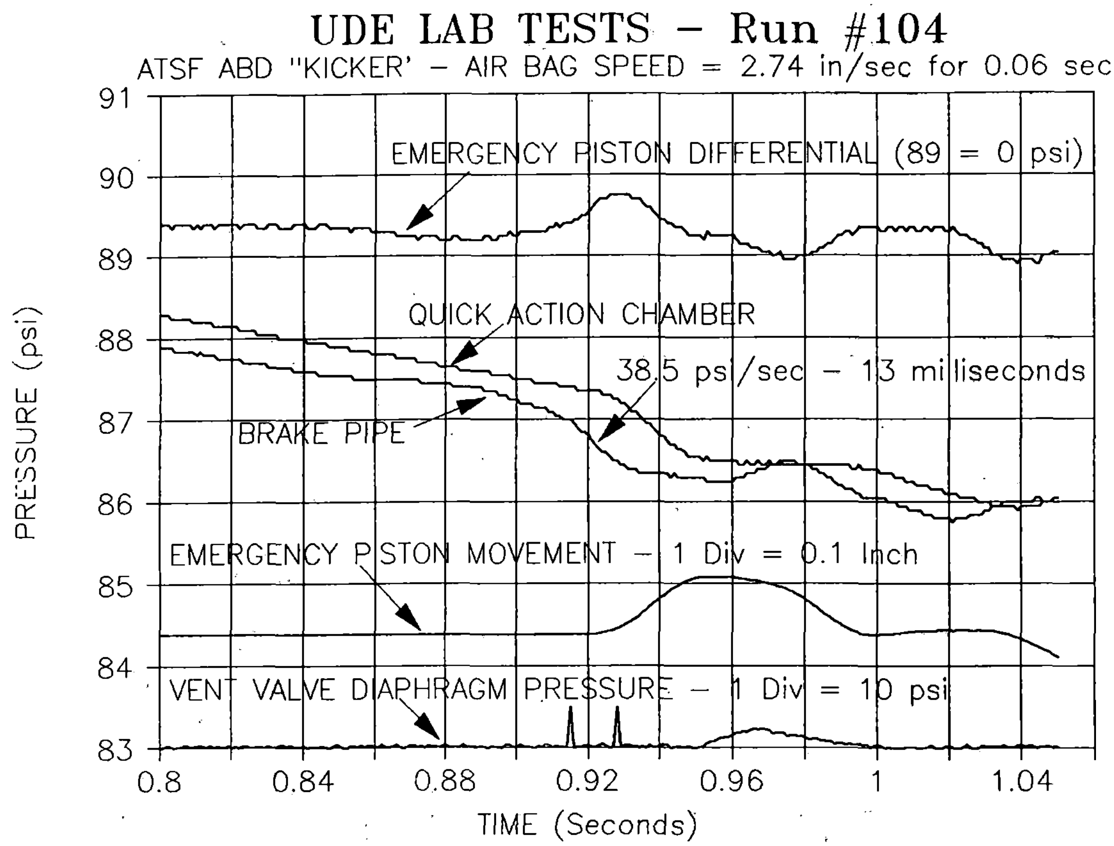


Exhibit 13.2

Because the Santa Fe valve was abnormally sensitive due to emergency slide valve wear, the remaining testing was done using the Union Pacific kicker, which is now of average sensitivity, and a Canadian Pacific ABD which was a confirmed kicker on the earlier Canadian Pacific train tests, but which has proven to be an average "good" valve. The minimum fluctuation rates necessary to cause an emergency application ranged from 40 psi/sec in 13 msec to 35.3 psi/sec in 20 msec for the Canadian Pacific valve, and 39.4 psi/sec in 14 msec to 36.1 psi/sec in 19 msec for the Union Pacific valve. Again, the brake pipe pressure rebound after the initial fluctuation distorts the picture. Exhibit 13.3 illustrates a case where the Canadian Pacific control valve very nearly went into emergency. Note that the emergency port of the emergency slide valve was open for 29 milliseconds, and the vent valve pressure built up to 20 psi. Normally, 32 to 36 psi will open the vent valve. Had the pressure continued to reduce at the initial quick service rate instead of rebounding, this reduction could very well have been an emergency.

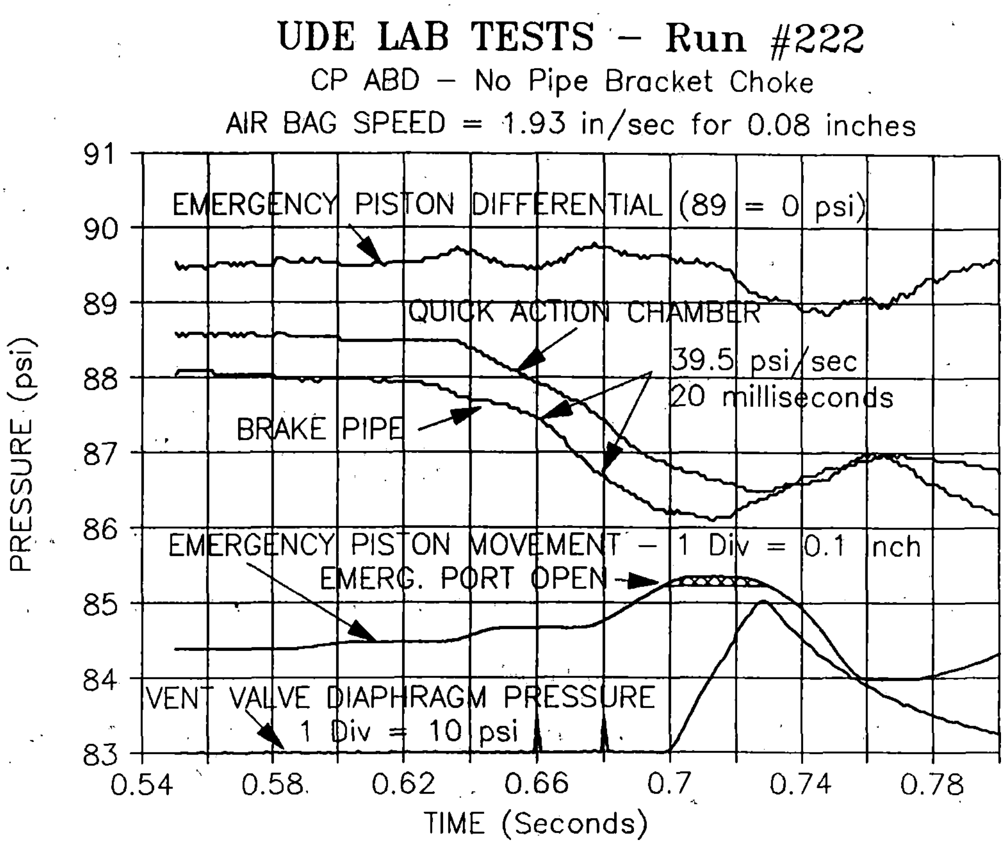


Exhibit 13.3

13.4 PIPE BRACKET CHOKES

One possible UDE cure is to use a choke between the pipe bracket and the emergency piston to slightly desensitize the emergency portion without significantly affecting emergency transmission speed. This was done using the Canadian Pacific valve as a baseline. A two by two inch piece of .030" thick galvanized sheet was drilled in the center, and this choke was placed against the center of the pipe bracket gasket between the pipe bracket and the emergency portion (Exhibit 13.4). The previous series of tests were then repeated to measure the change in valve sensitivity due to the pipe bracket choke.

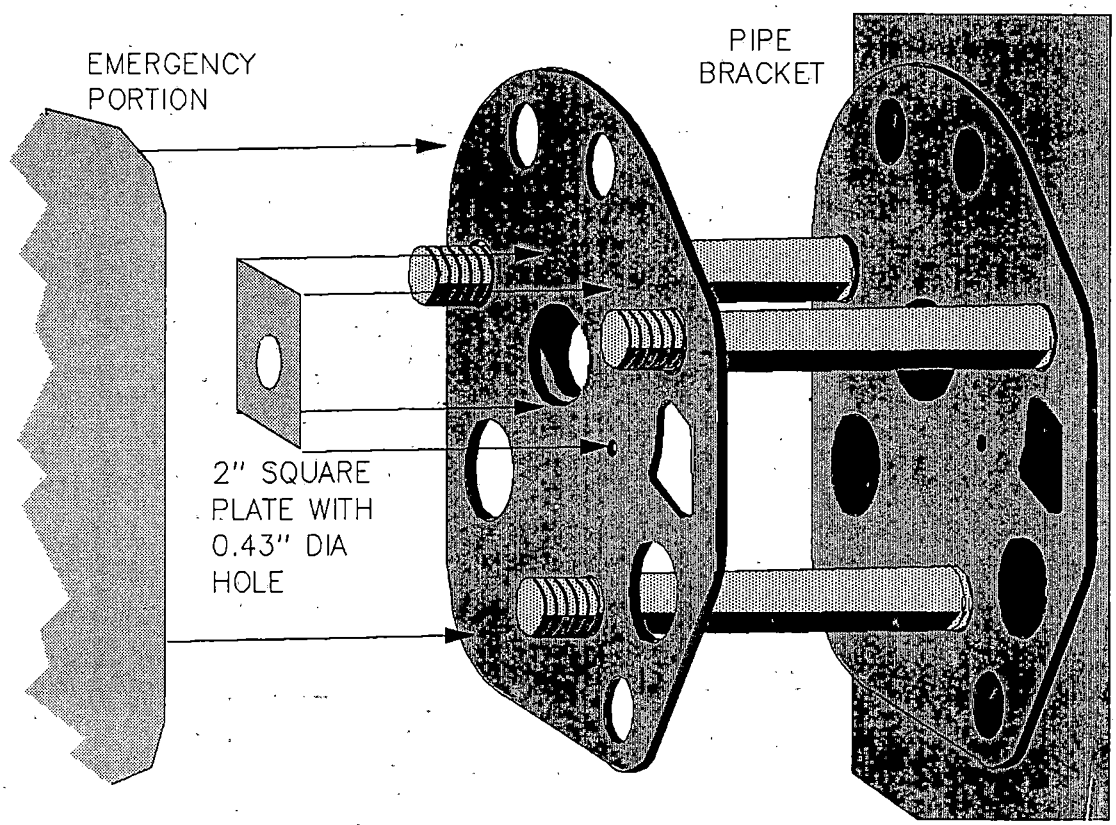


Exhibit 13.4

The initial choke size tested was 0.25" diameter, which to our surprise was too small. The choke diameters were then increased from 0.25" to 0.313", 0.36", and finally to 0.43". Exhibit 13.5 is a plot of the unstable emergency fluctuation rates and the stable service fluctuation rates versus time duration for the no choke condition and for the 0.43" diameter choke. Curves have been drawn through the lowest emergency rates and the highest service rates.

UDE LAB TESTS - CP ABD

MAXIMUM STABLE AND MINIMUM UNSTABLE PRESSURE FLUCTUATION RATES
No Pipe Bracket Choke vs. 0.43" Dia. Choke.

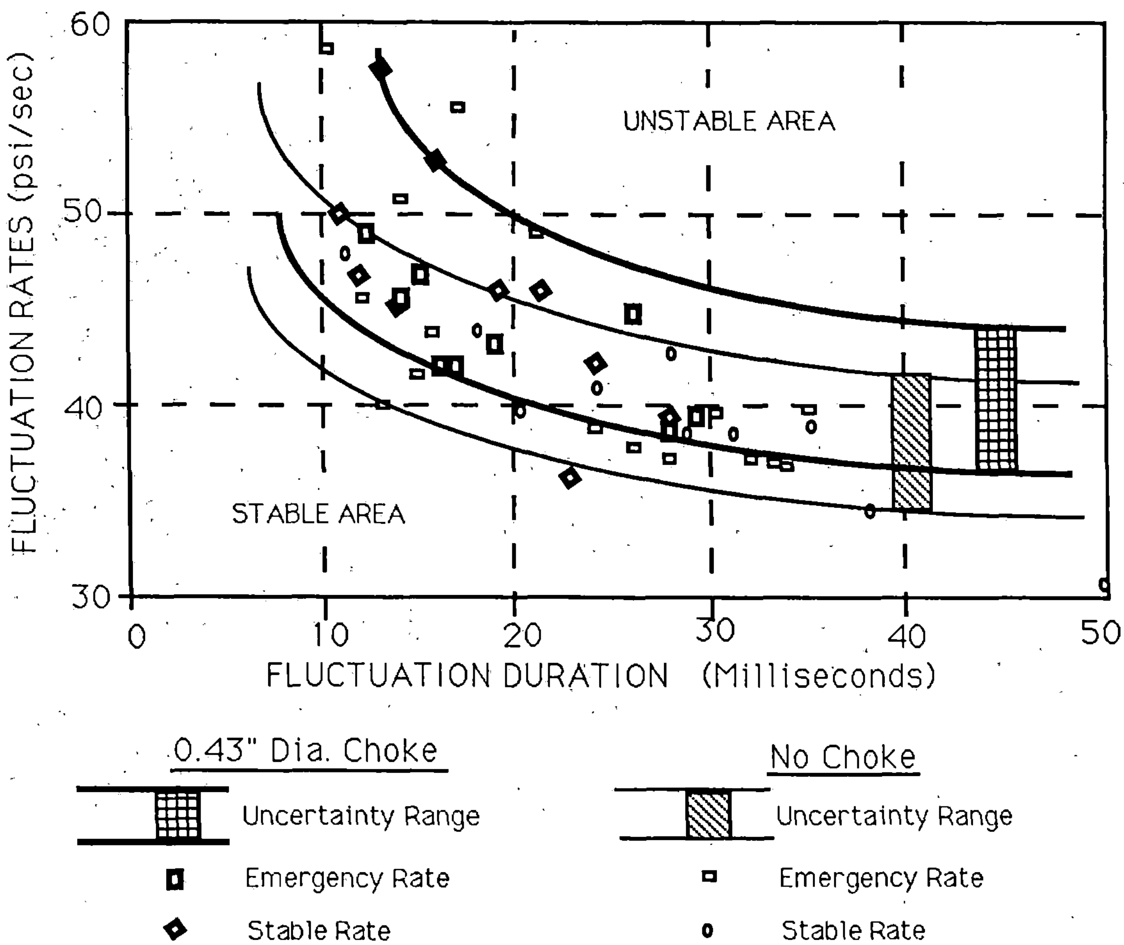


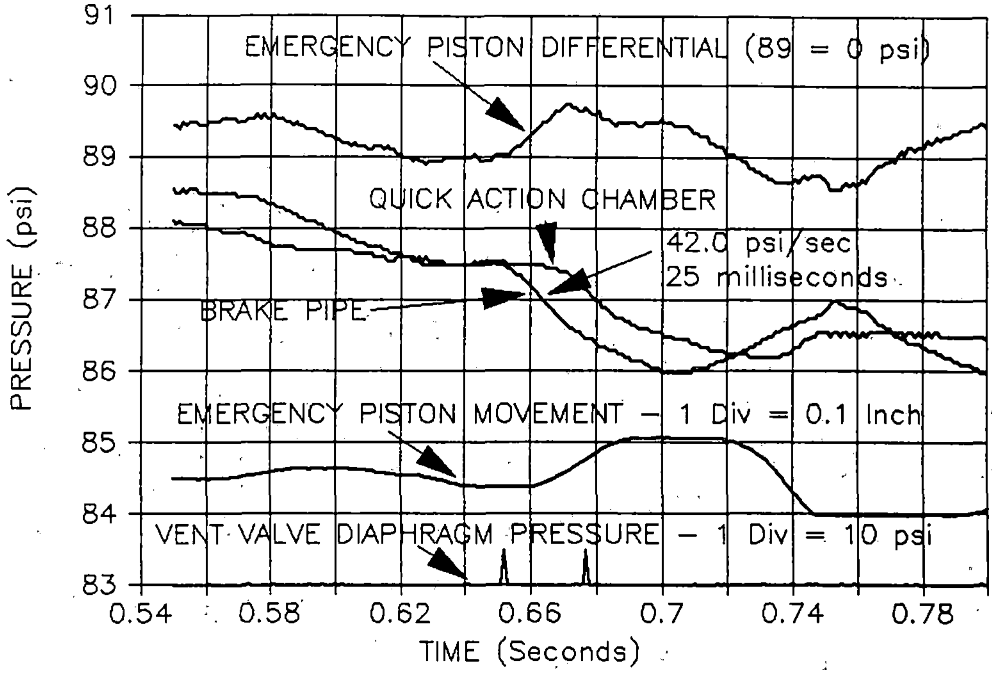
Exhibit 13.5

Note that there is an area where the service and emergency rates overlap. For each choke condition, the overlap range is about 8 to 10 psi/sec. Inside of this range, a control valve may or may not go into emergency. Exhibit 13.6 illustrates this point.

Both are tests made with the 0.36" diameter pipe bracket choke. Test Run #297 shows a rapid reduction of 42.0 psi/sec lasting for 25 msec, and Run #299 shows a rate of 36.8 psi/sec lasting for 19 msec. In Run #299, the emergency slide valve was in emergency position for 43 msec, and the vent valve diaphragm pressure reached 27.5 psi. The emergency slide valve is in emergency position when the vent valve diaphragm pressure begins to build, and the slide valve is in service position when the vent valve diaphragm pressure is being exhausted (on an ABD or ABDW valve, the emergency port of the emergency slide valve opens when the emergency piston moves about 0.12 inches). In this case, the valve very nearly went into emergency, and probably would have if the brake pipe pressure had not rebounded and moved the emergency piston back to service position. Yet the previous reduction during Run #297 had a higher reduction rate lasting for a longer time period, but the emergency slide valve did not move into emergency position. The only significant difference between the two reductions is the position of the emergency piston when the MTS-induced reduction occurred. During Run #297, the piston was 0.081 inches from emergency position, and did not reach emergency. But in Run #299, the piston was 0.074 inches from emergency, and did reach emergency position. There were many

UDE LAB TESTS – Run #297

CP ABD – .359" Dia. Pipe Bracket Choke
2.72 in/sec for 0.07 sec



Run #299

AIR BAG SPEED =2.52 in/sec for 0.06 sec

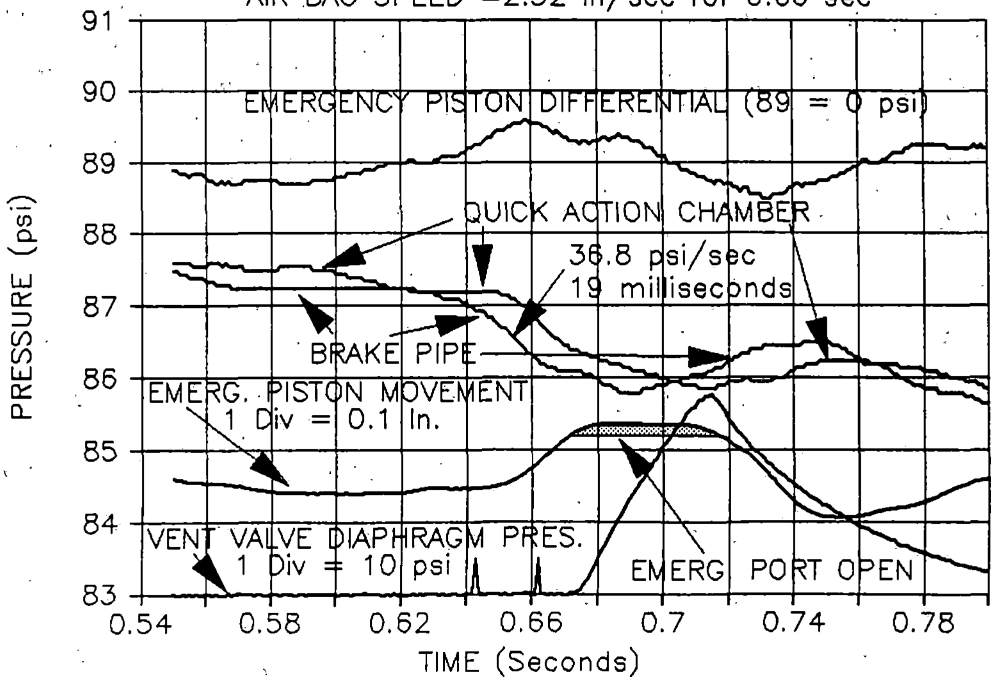


Exhibit 13.6

other cases such as this where the factor determining whether or not a valve would go into emergency was the position of the emergency slide valve when the fluctuation occurred, the movement or lack of movement of the slide valve when the fluctuation occurred, and the frictional force between the slide valve and the valve seat. Exhibit 13.7 is a diagramatic showing how both the service and emergency ports can be open at the same time. This is what occurred during test # 299.

So even though a range of uncertainty exists, this range can be seen to move up or down with different sized pipe bracket chokes on a valve sensitivity plot like that in Exhibit 13.5.

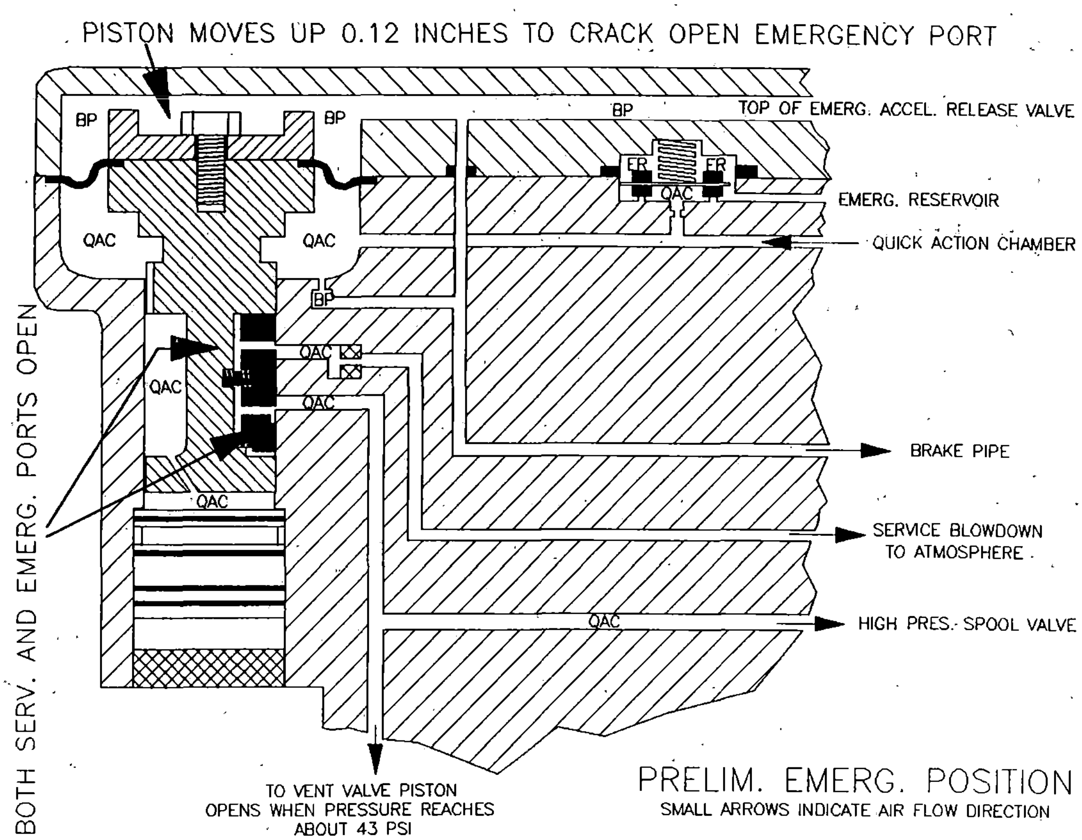
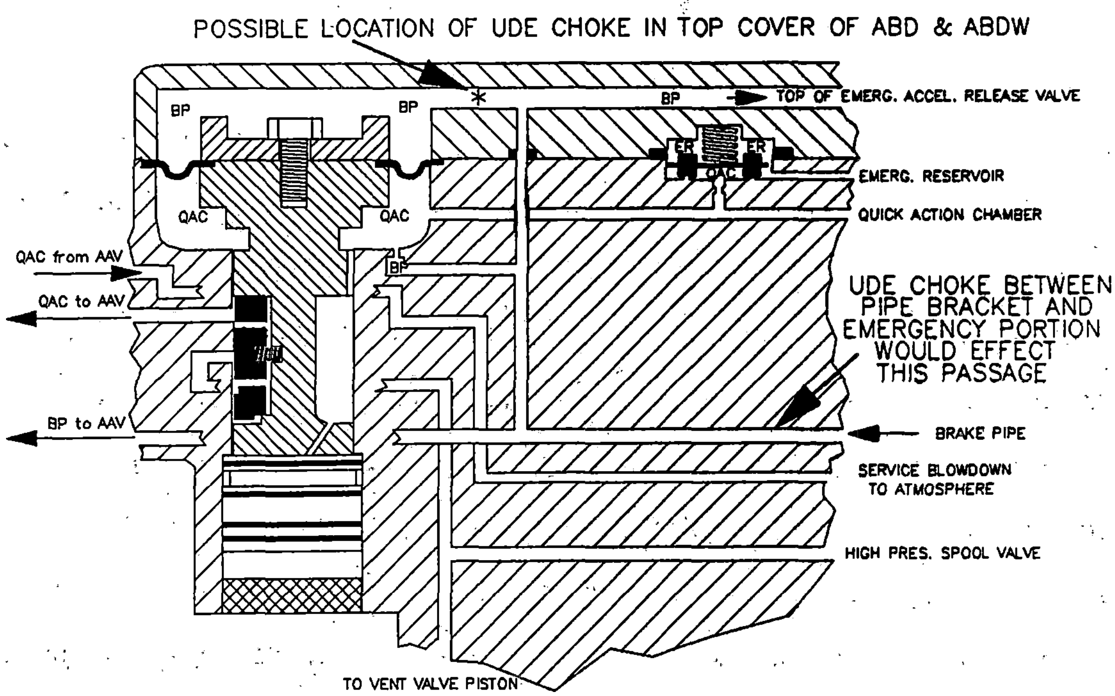


Exhibit 13.7

There was some concern that a choke placed in the pipe bracket would reduce the emergency propagation rate of an intended emergency application. To check this, some preliminary tests were conducted on the 150 car test rack of NYAB. The tests used 50 cars equipped with ABDW control valves. The tests revealed that there would be no significant reduction of emergency propagation rates for a 50 car train. However, when a minimum service application was made, the service propagation time for the 50 car train increased from 12.6 seconds to 15.2 seconds. This would be clearly unacceptable. This loss of service braking performance of the ABDW is due to the placement of the choke. When placed between the emergency portion and the pipe bracket, it not only effects the emergency piston, but also effects the breathing of the accelerated application valve (AAV).

So, if the choke cure proves itself effective, the choke may have to be located in the top cover of the ABDW emergency portion. In this position the choke should have no effect on the AAV activity of the ABDW. For the AB or ABD valve, a choke located between the pipe bracket and the emergency portion would not affect the service transmission times. Additional testing has been done on 150 car test racks to investigate the effect the choke will have on transmission times in long trains and the ability to jump cut-out control valves. This will be covered in a later section of this report. Exhibit 13.8 shows a diagramatic of the ABDW emergency portion, and the two possible locations of the choke. This exhibit also shows how the pipe bracket location of the choke would affect the brake pipe passage to the AAV.



ABDW in RELEASE POSITION

Exhibit 13.8

14.0 FRA TRANSPORTATION TEST CENTER SLACK TESTS

14.1 INTRODUCTION

Up to this point, the results from the field tests and from the laboratory tests which where conducted concurrently had led to the following conclusions;

1. Most UDEs are caused by a control valve which responds to a rapid pressure reduction of short duration by going into emergency position. These rapid pressure reductions normally act in conjunction with normal service brake applications to produce UDEs. In most cases, this happens with control valves which are in "good" condition and pass all applicable AAR air brake tests.
2. These rapid short duration pressure reductions are caused by slack action. More specifically, they are caused by the sequential deceleration of cars at a closure rate approximately equal to the speed of sound within the brake pipe.
3. In lab tests, control valves in normal operating condition may go into emergency in response to reduction rates of 30 to 40 psi/sec lasting from 10 to 15 milliseconds.
4. **Control valves can be conditioned to be less responsive toward these rapid, short duration reductions through the use of a 0.43" diameter choke placed in the central air passage between the pipe bracket and the emergency portion.**

The purpose of the FRA funded portion of the UDE study was to conduct a train test under very controlled conditions at the Transportation Test Center at Pueblo, Colorado. The test was designed to accomplish the following;

1. Verify that slack action can cause pressure reductions of the magnitude and duration necessary to produce UDEs.
2. Evaluate the performance of 0.43" dia. chokes in actual train service.

14.2 THEORY

The University of New Hampshire computer model predicted the occurrence of negative pressure pulses of 0.1 to 0.2 psi due to the sudden deceleration of a car. This is due to the mass of the air in the brake pipe obeying Newton's Laws of Motion. When a car and the brake pipe attached to it decelerates, the air within the brake pipe continues to move at its initial speed. This causes a pressure reduction to occur behind the decelerating car, and a pressure increase to occur ahead of the decelerating car. These reductions and increases take the form of a pulse, the magnitude and duration of which are directly proportional to the magnitude and duration of the deceleration.

When the slack runs in on a train at a closure rate of approximately the speed of sound in the brake pipe, the negative pressure pulses moving back in the train can add to one another. In other words, if a pulse generated by the deceleration of car A reaches car B just as it decelerates and creates its own negative pulse, the pulse from car A adds to the pulse from car B. When this process is carried through a train, the computer model predicted the occurrence of pressure reductions of up to 1.6 psi due to slack action alone. It also predicted the doubling of these pulses to as much as 2.6 psi as they reached the rear angle cock, and the reflection of these pulses forward in the train. Deceleration rates of about 2.0G lasting for 0.12 seconds were needed to create UDEs.

Laboratory testing at the AAR Chicago Technical Center (CTC) has shown that control valves in good working order will go into emergency in response to pressure reduction rates of 30 to 40 psi/sec lasting for 10 to 15 milliseconds. Testing has also shown that the placement of a choke in the brake pipe air passage leading from the pipe bracket to the top of the emergency piston can lessen the effect of a rapid short duration pressure pulse. The optimum choke size developed from lab testing was of 0.43 inch diameter. This choke plate was placed over the center air passage between the emergency portion and the pipe bracket. The use of choke plates or their equivalent was considered a possible fix for most UDEs. However, some question remained whether these chokes would decrease the emergency propagation rate to the extent that they would be unusable in service.

UDEs commonly occur most often on TOFC/COFC trains. This may be due to the increased potential for harsh slack action on these trains due to the widespread use of end-of-car cushioning devices, some of which may be defective. In addition, the present AAR air brake tests are less critical with longer cars, so the possibility of bad control valves being on long cars is greater.

The FRA funded UDE train test at Pueblo was designed to investigate all of the above factors.

14.3 TEST CONSIST

The test train was to have consisted of 3 high horsepower locomotives, forty-six 85 to 89 foot long empty flat cars and four 100 ton loaded hoppers. The hoppers were necessary to mount the dynamometer couplers needed to monitor the in-train forces, and they were loaded simply because these cars were on-hand and available from another test at TTC. Due to car delivery problems the final test train consisted of 32 long empty cars and the four loaded hoppers. In addition, five un-braked loaded 100 ton hoppers were placed at the rear of the train during the initial test runs to generate high buff forces. This consist was modified during the course of the test. Exhibit 14.1 illustrates the consist variations.

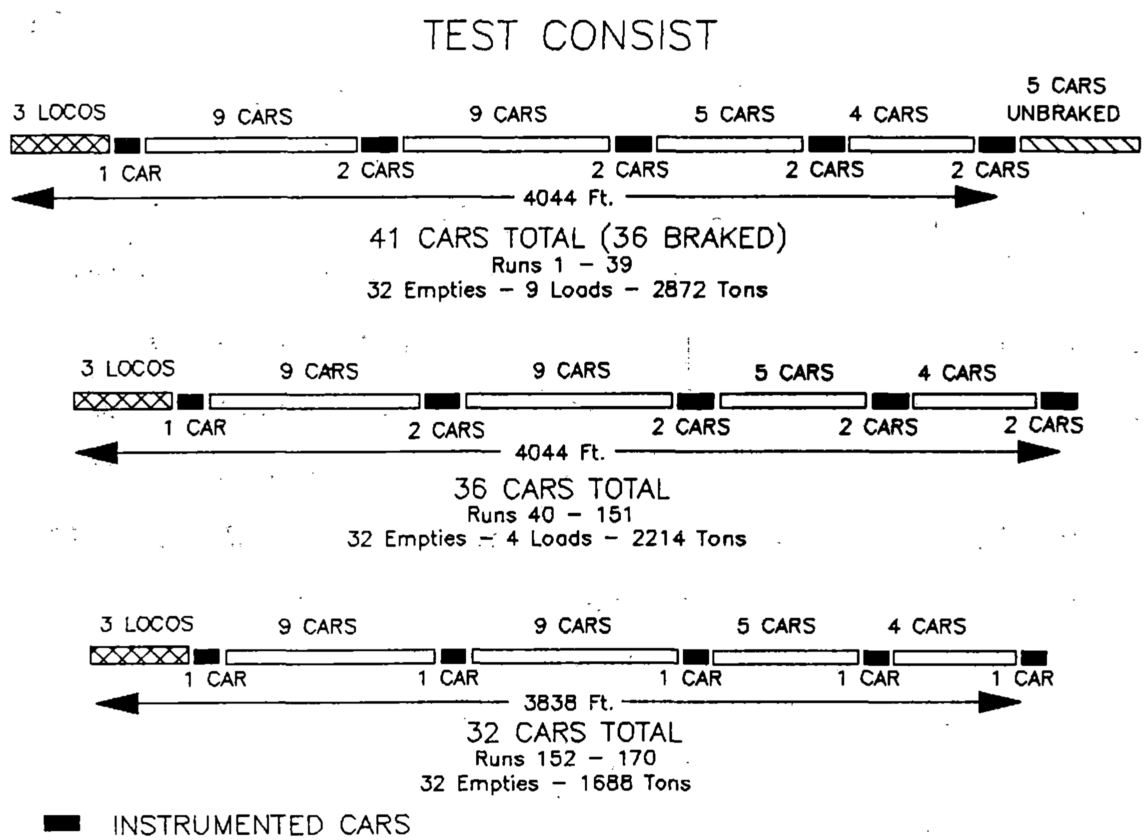


Exhibit 14.1

14.4 TEST INSTRUMENTATION

The instrumentation cars shown in Exhibit 14.1, with the exception of the 1st car, consisted of one loaded 100 ton hopper and one empty 89 foot auto rack. A dynamometer coupler and a string potentiometer were mounted on the trailing ends of the last locomotive and the four loaded hoppers to measure buff forces and coupler displacement. The following flat cars also carried a string potentiometer, so the total relative movement of the dynamometer coupler and its mating coupler on the flat car could be recorded. The flat cars also carried pressure transducers to measure brake pipe pressure at the dirt collector bowl and brake cylinder pressure at the cylinder. For the later test runs, an accelerometer was installed on the middle instrumented flat car (first car 23, then during later tests car 21). All of this instrumentation was cabled up to a pulse coded modulation (PCM) transmitter on car 23 (later car 21). Use of the PCM system allowed real time comparison of the 10 pressures, 5 coupler forces and 10 coupler displacements. In addition to the 25 data channels already mentioned, there were also channels allotted to record an event timer, an accelerometer, and two more pressure transducers, for a total of 29 data channels. Also, a 22 inch clear plastic UDE detector hose was installed on the leading end of every car so that if a UDE occurred, the originating car could be positively identified.

The PCM data was recorded at 1200 samples per second. The data was transmitted to the computer room in the Roll Dynamics Laboratory and stored on tape for later analysis. However, eight of the 29 data channels could be plotted real time on a strip chart recorder with a very high frequency response. This enabled the test engineer in the computer room to monitor coupler buff data and the brake pipe pressure data, and use the information to quickly set the parameters for the next test run. Exhibit 14.2 is a list of data channels for the initial test conditions.

Exhibit 14.2

Data Channel Allocation

CHANNEL #	MEASUREMENT	LOCATION
1	COUPLER FORCE	REAR OF LOCO CONSIST
2	COUPLER MOVEMENT	REAR OF LOCO CONSIST
3	COUPLER MOVEMENT	FRONT OF 1st CAR
4	BRAKE PIPE PRESSURE	1st CAR
5	BRAKE CYL. PRESSURE	1st CAR
6	COUPLER FORCE	REAR OF 11th CAR
7	COUPLER MOVEMENT	REAR OF 11th CAR
8	COUPLER MOVEMENT	FRONT OF 12th CAR
9	BRAKE PIPE PRESSURE	12th CAR
10	BRAKE CYL. PRESSURE	12th CAR
11	COUPLER FORCE	REAR OF 22nd CAR
12	COUPLER MOVEMENT	REAR OF 22nd CAR
13	COUPLER MOVEMENT	FRONT OF 23rd CAR
14	BRAKE PIPE PRESSURE	23rd CAR
15	BRAKE CYL. PRESSURE	23rd CAR
16	COUPLER FORCE	REAR OF 29th CAR
17	COUPLER MOVEMENT	REAR OF 29th CAR
18	COUPLER MOVEMENT	FRONT OF 30th CAR
19	BRAKE PIPE PRESSURE	30th CAR
20	BRAKE CYL. PRESSURE	30th CAR
21	COUPLER FORCE	REAR OF 35th CAR
22	COUPLER MOVEMENT	REAR OF 35th CAR
23	COUPLER MOVEMENT	FRONT OF 36th CAR
24	BRAKE PIPE PRESSURE	36th CAR
25	BRAKE CYL. PRESSURE	36th CAR
26	ACCELERATION	23rd CAR
27	B. C. PIST. TRAVEL	23rd CAR
28	MANUAL EVENT MARKER	
29	V. V. PISTON PRES.	LAST CAR

14.5 SLACK RUN-IN TEST PROCEDURE

The initial series of test runs consisted of applying various mixtures of dynamic and air braking to the train at selected track locations in order to produce harsh slack action (a detailed test log is given in Appendix C). All moving slack run-in tests were done on tangent portions of the Transit Test Track (TTT, shown in Exhibit 14.3) at speeds no higher than 30 mph. The buff forces throughout the train were closely monitored during all but the last test runs. A maximum buff force limit was initially set at about 350,000 lbs, but during the course of the test sustained buff forces of 400,000 lbs. and peak forces of 750,000 lbs. were recorded without derailing the train. Exhibit 14.4 gives a listing of the test parameters and the consist make-up.

The slack run-in was created in two ways. The first attempts consisted of running in a counterclockwise direction around the TTT and applying the dynamic brake in notch 8 and a minimum brake application when the first two thirds of the train was on a downgrade and the rear third on a slight upgrade (locomotives between T40 and T43, Exhibit 14.3). Later attempts consisted of accelerating hard up to 30 mph at the foot of a 1.5% grade (T14, Exhibit 14.3), and making the dynamic and air brake applications as the locomotives started upgrade. Every attempt was made to time the air brake application so that quick service activity would coincide with the slack run-in at one of the instrumented flat cars. This proved difficult even under these relatively controlled conditions. The best results were obtained

without using the five un-braked "hammer" cars.

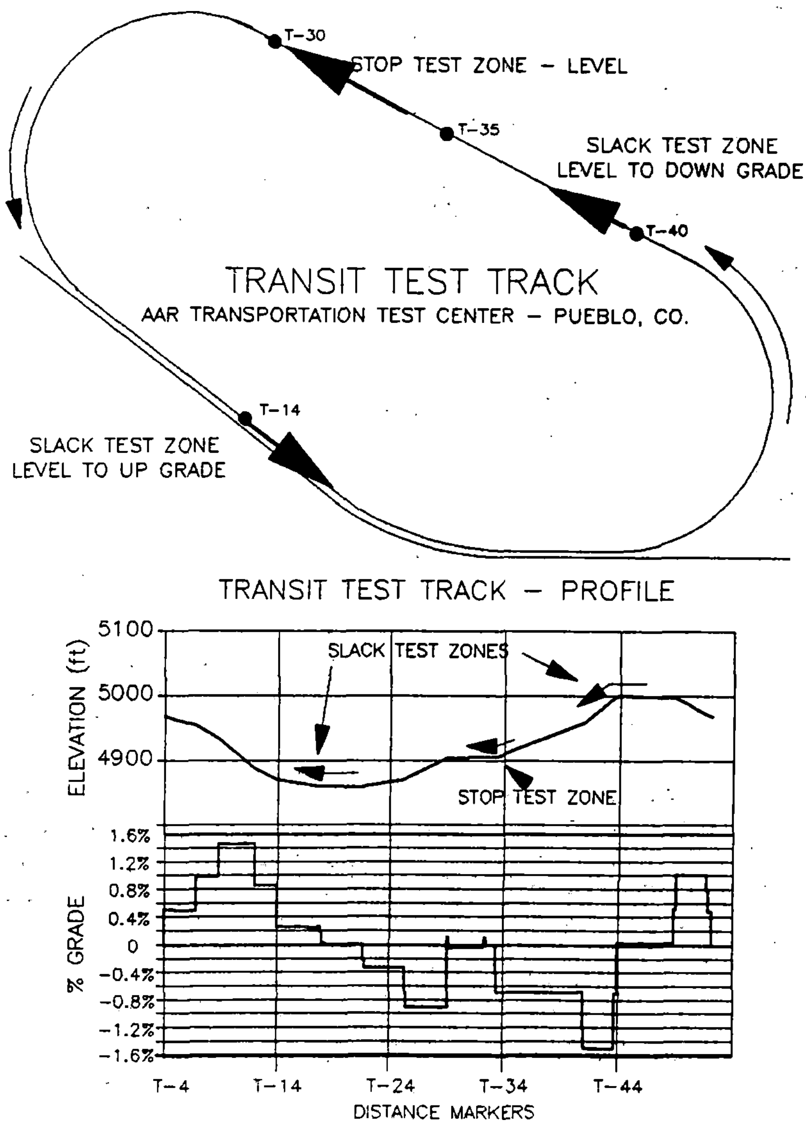


Exhibit 14.3

Exhibit 14.4

TEST NO.	TEST TYPE	# OF CARS	TOTAL WEIGHT (tons)	TRAIN LENGTH (feet)	BP LENGTH Cars Only (feet)
1-39	SLACK TESTS	32 FLATS 4 HOPPERS 5 HAMMERS*	2872	3897	4044
40-45	EMERGENCY STOP TESTS	32 FLATS 4 HOPPERS	2214	3647	4044
46-116	TOES TESTS**	32 FLATS 4 HOPPERS	2214	3647	4044
117-122	EMERGENCY STOP TESTS	32 FLATS 4 HOPPERS	2214	3647	4044
123-143	SLACK TESTS	32 FLATS 4 HOPPERS	2214	3647	4044
144-151	FULL SERV. STOP TESTS	32 FLATS 4 HOPPERS	2214	3647	4044
152-170	SLACK TESTS	32 FLATS	1688	3185	3838

Test runs 117-170 were with the pipe bracket chokes installed.

* "Hammer" cars were 100 ton loaded hoppers with the brake pipe angle cock closed ahead of them and brake systems drained.

** These tests were run to validate the Train Operations Energy Simulation model. Full service stop tests without pipe bracket chokes were among the tests made. These tests were compared with the stop tests made in test runs 144-151.

During the later stages of the test the slack run-ins were created by violently backing the locomotives into the standing train, which was parked on level tangent track with the slack stretched. The locomotive independent brake cylinder pressure was adjusted up to 82 psi and with the independent brake applied, the throttle was quickly advanced to notch 8 in reverse. When the locomotive began to move, the independent brake was released, and the units backed rapidly into the train. The best results were obtained when all of the loaded 100 ton hoppers (with the dynamometer couplers) were removed from the train, the front two thirds of the train was stretched and the rear third of the train was bunched. This method resulted in slack run-in rates approaching the speed of sound in the brake pipe. The stationary test method was necessary due to the relative shortness of the train. If the test train had been 50 cars long as originally intended, the slack run-in rate at the rear of the train would have been higher during the moving tests, and this stationary method probably would not have been necessary.

14.6 DISCUSSION OF SLACK RUN-IN TEST RESULTS

Exhibit 14.5 is a plot of the data from test run 33. All of the subsequent data plots in this report will follow this format. The pressure plots are on a scale which indicates each major horizontal division as 2 psi. This gives no indication of the actual pressure or gradient. Due to slight differences in each pressure transducer, the actual pressure and gradient can only be estimated at about 89 psi and 1/2 psi respectively. Below the pressure plots are plots of the coupler displacement on the leading coupler of each pressure transducer equipped car. Note that from very early in the test the string potentiometer on the lead flat car was inoperative. This was not noticed due to the necessity of closely monitoring the brake pipe pressure and buff forces in each test. The plots are laid out so that cause and effect can be determined, and pressure pulse movement in the brake pipe can be clearly seen.

Test run 33 was made by accelerating up to 30 mph as the locomotives reached marker T14 (Exhibit 14.3) then applying notch 8 dynamic brake as quickly as possible. A minimum brake application was made when the motor amperage reached 250 amps. This resulted in a peak buff force of 650,000 lbs. on car 22, and a sustained buff force of about 300,000 lbs.

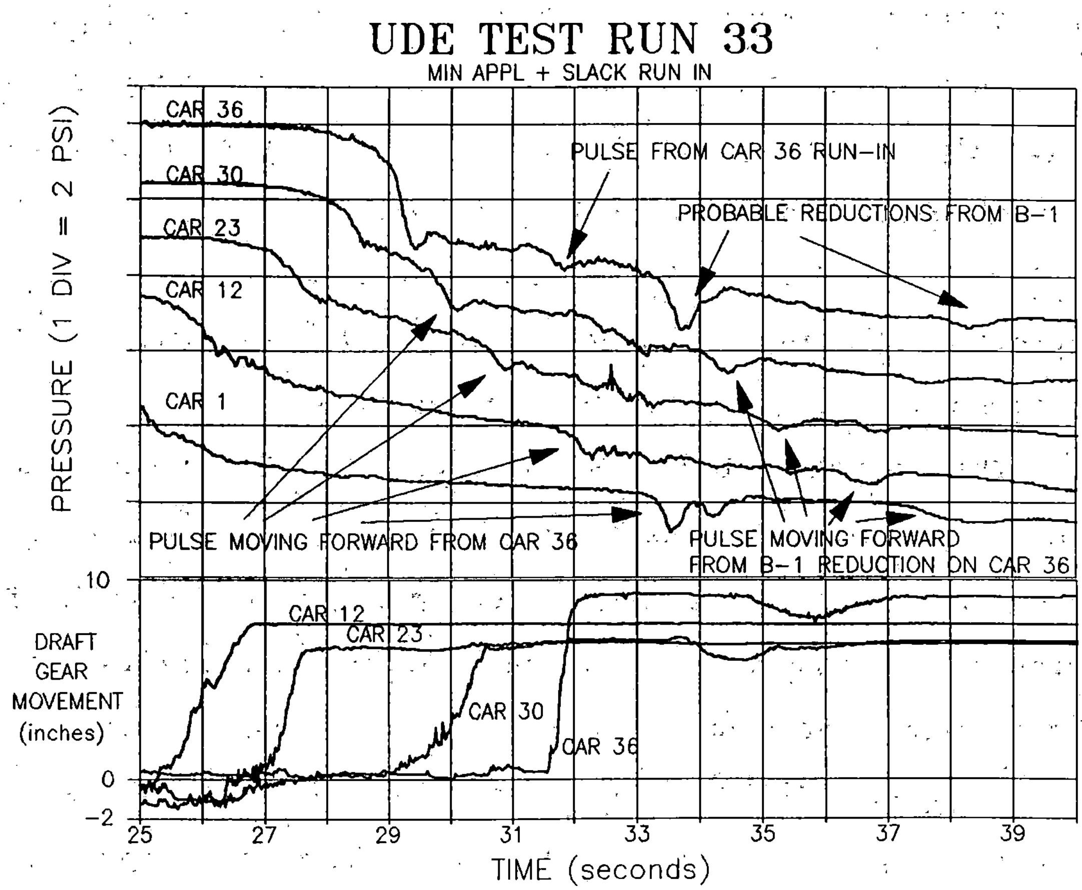


Exhibit 14.5

The slack run-in was not as rapid as some of the later test runs. The coupler on car 36 closed at about 22.5 inches per second compared to 50 inches per second on later test runs. Yet a negative pressure pulse was generated on car 36 at 31.7 seconds. The pulses generated on car 36 at 29.4, 33.7 and 38.2 seconds are thought to be the result of B-1 quick service valve cycling. Note that this seems to trigger the B-1 valves ahead with the result that a pulse moves from the rear car to the front of the train. The pulse gets stronger at the front of the train (33.6 seconds), continues to the front angle cock and then reflects back into the train (34.2 seconds). This phenomenon was noticed even on brake applications made on the standing train.

Exhibit 14.6 is a comparison of brake pipe pressure plots from a minimum brake application on a standing train and on a train experiencing a heavy slack run-in. Test run 107, a minimum application on the stationary train, shows traces commonly seen on stationary 150 car test racks with the exception of the B-1 activity mentioned previously. Test run 143 was a minimum brake application made 4.5 seconds after notch 8 power application in reverse direction on a standing train with the slack stretched. The effect of slack run-in can clearly be seen at the 23rd car 13 seconds into the run, and at 36th car 16.5 seconds into the run.

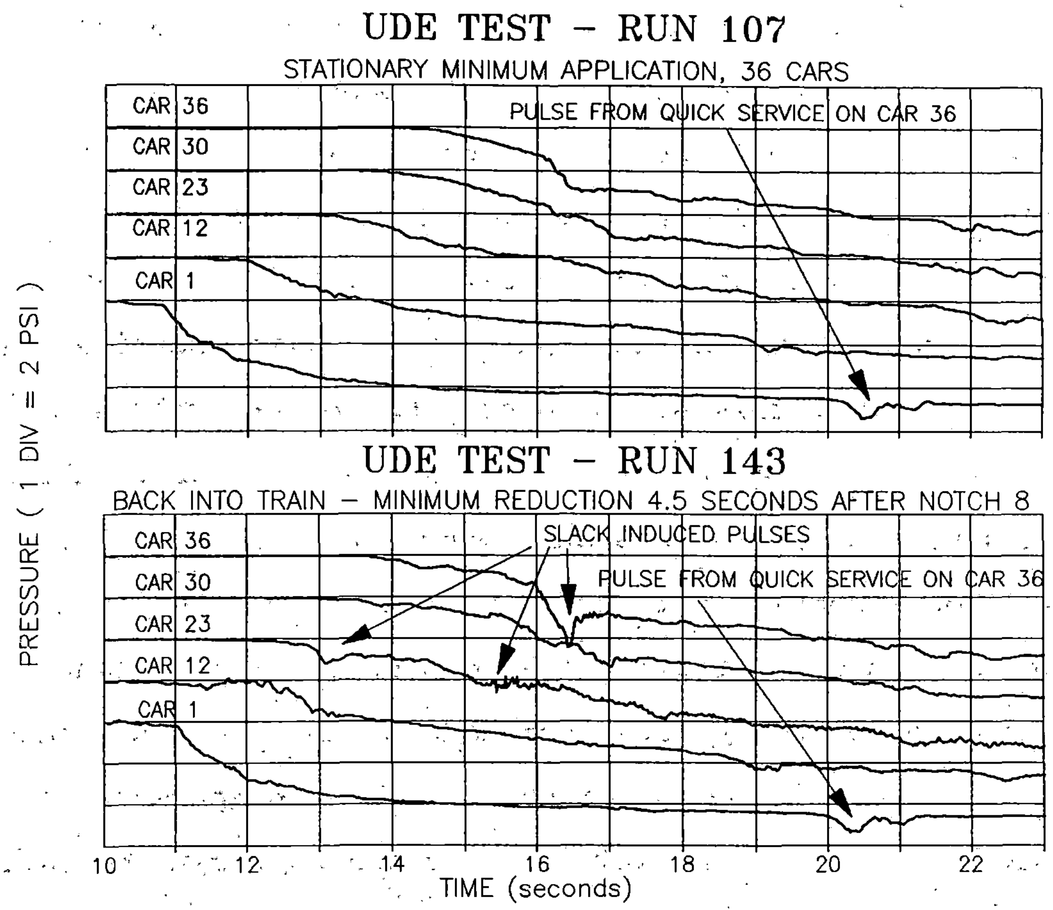


Exhibit 14.6

Exhibit 14.7 is a data plot of test run 134. This run was similar to run 143 except the minimum application was 5 seconds after the reverse power application. An accelerometer mounted on the 23rd car recorded a 0.6G deceleration for 40 milliseconds. In this case the run in of car 12 (coupler closing at about 22 in/sec) produced a negative pressure pulse of about 0.4 psi. This pulse moved back to car 23 and was reinforced by the run-in of that car, then continued back until it reached the rear car causing a full one psi reduction 14.5 seconds into the run. At 15.7 seconds car 36 ran-in (coupler closed at about 32 in/sec) causing a sharp 1.3 psi reduction. This reduction was on top of a 0.6 psi reduction caused by the cars ahead, which resulted in a total reduction of 2 psi. Note that all of these reductions are entirely due to slack action. The actual minimum reduction doesn't reach car 36 until 18.4 seconds into the run, a full 4.2 seconds after the slack induced reduction begins.

The maximum overall brake pipe pressure reduction rate generated by the run-in of the 36th car at 15.7 seconds was 27 psi/sec for 20 milliseconds. This rate is at the lower threshold of the rates necessary to produce UDEs of good valves in lab tests.

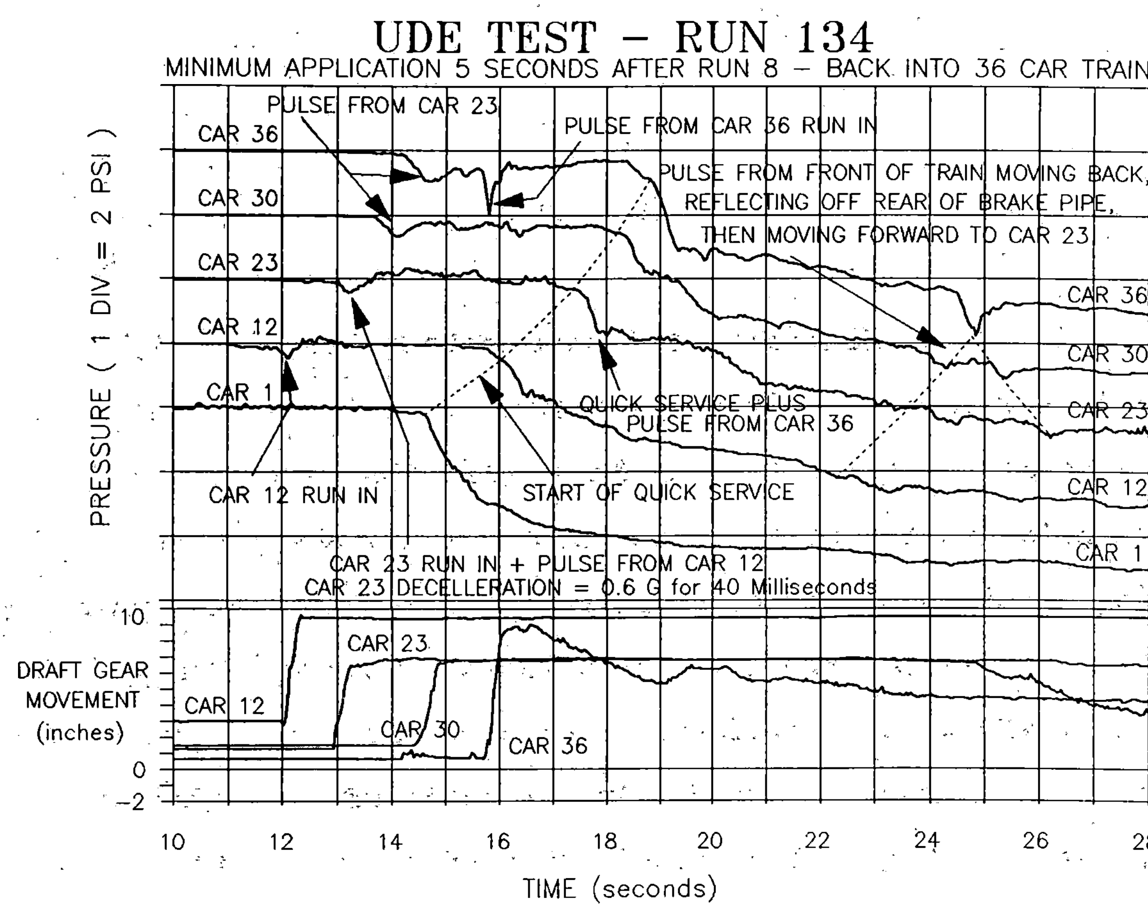


Exhibit 14.7

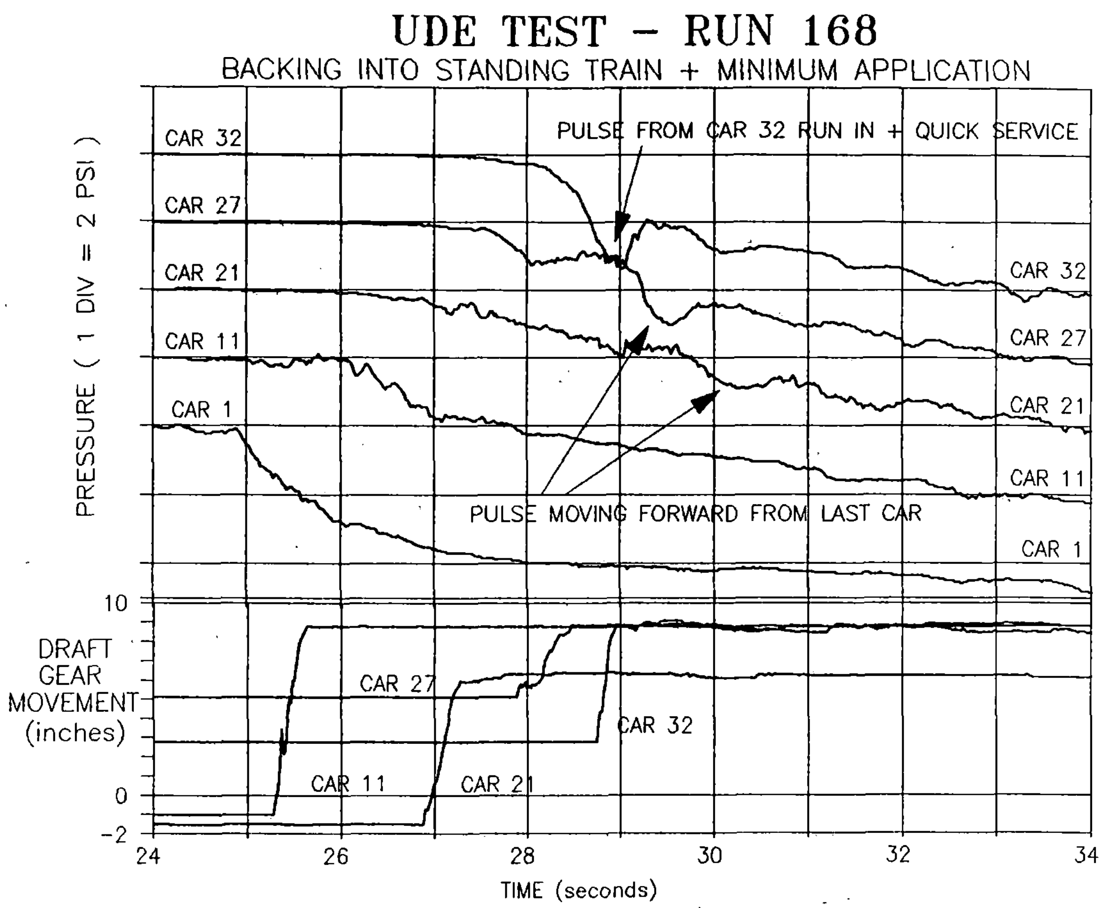


Exhibit 14.8

Test run 168 (Exhibit 14.8) was another test in which the locomotives were backed into the train. In this case the front two thirds of the train was stretched, and the rear third was bunched prior to the start of the test. The loaded hoppers carrying the dynamometer couplers were not in the train, which resulted in a 32 car train of empty flats. This was done in order to maximize the acceleration of each car. A minimum brake application was made 2 seconds after release of the independent brake. Note that the slack run-in rate of about 750 ft\sec was still less than the speed of sound in the brake pipe (in this case about 980 ft/sec at 50 Deg. F.). A longer train would have faster slack closure rates at the rear end than the rates generated by the 32 car test train.

Test run 168 resulted in the run-in pulses from the cars ahead and the run-in pulse from the 32nd car coinciding almost exactly with the start of quick service activity on the 32nd car. This produced a pressure reduction from all causes of about 3.2 psi in one second. However, the maximum reduction rates were only about 7.5 psi/sec on the 32nd car.

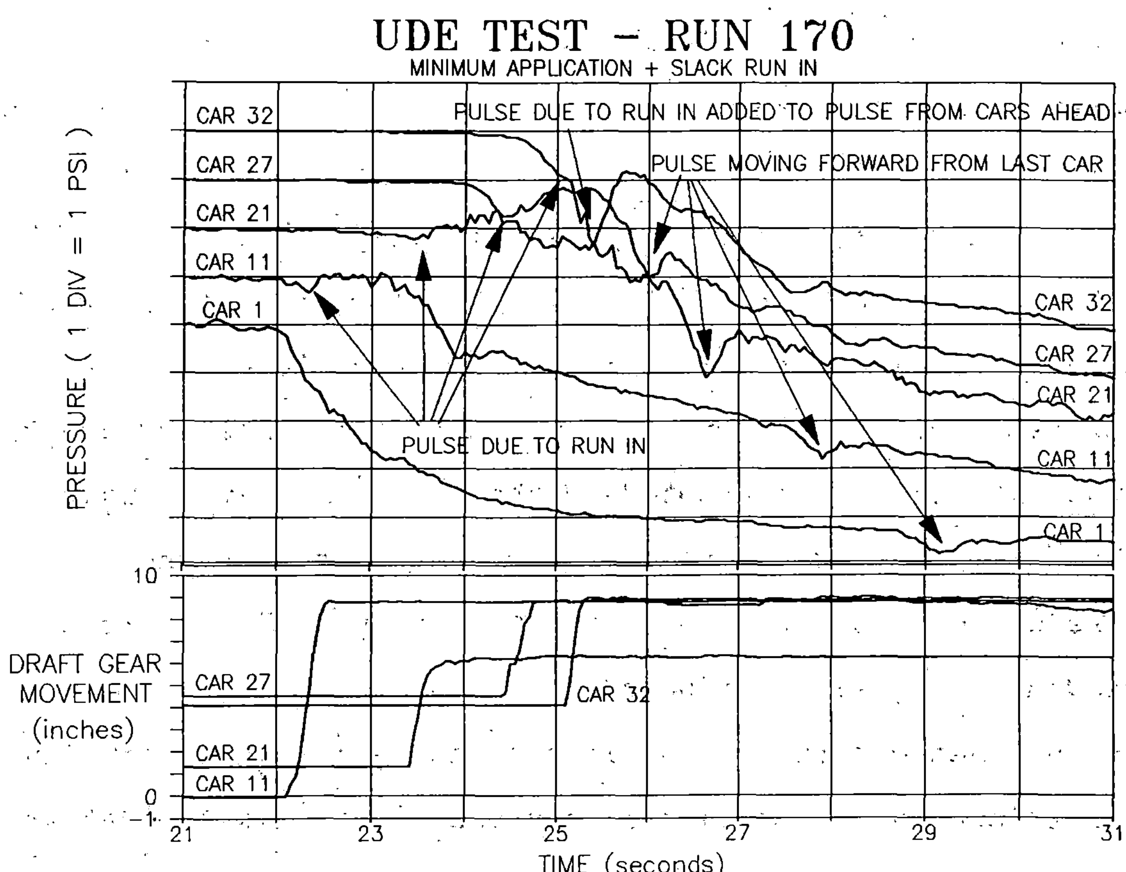


Exhibit 14.9

Test run 170 (Exhibit 14.9) was a repeat of run 168, but the overall reduction of 2.3 psi was smaller and the maximum reduction rate of 32 psi/sec was much higher.

This illustrates the basic problem in understanding UDEs. The occurrence of most UDEs depends on a great many factors, all of which must act together to produce a UDE. The slack run-in should be at or near the speed of sound in the brake pipe for at least a portion of the train and the run-in pulse should ideally coincide with the quick service activity at a particular valve. In addition, lab tests have shown that a valve may or may not go into emergency in response to a given reduction rate (see Exhibit 13.5). Even under the relatively controllable conditions at TTC as compared to revenue train tests, it was extremely difficult to repeatedly line up all factors to even get repeatable results.

Exhibit 14.10 illustrates the sensitivity curves established during the previously described lab tests along with the maximum reduction rates recorded during the slack tests at TTC. For test runs 123 through 170 the borderline ATSF "kicker" ABD emergency portion was mounted on the last car of the train where the maximum pressure pulses occurred. Note that the maximum reduction rates recorded at TTC were just short of the rates needed during lab testing to cause an emergency application. Because the curves in the lab tests might actually be somewhat lower under service conditions, it is likely that the maximum reduction rates recorded at TTC were in the bottom segment of the "go/nogo" range of a standard valve. Once again, a longer train might have produced the accelerations and maximum reduction rates needed for the generation of UDEs.

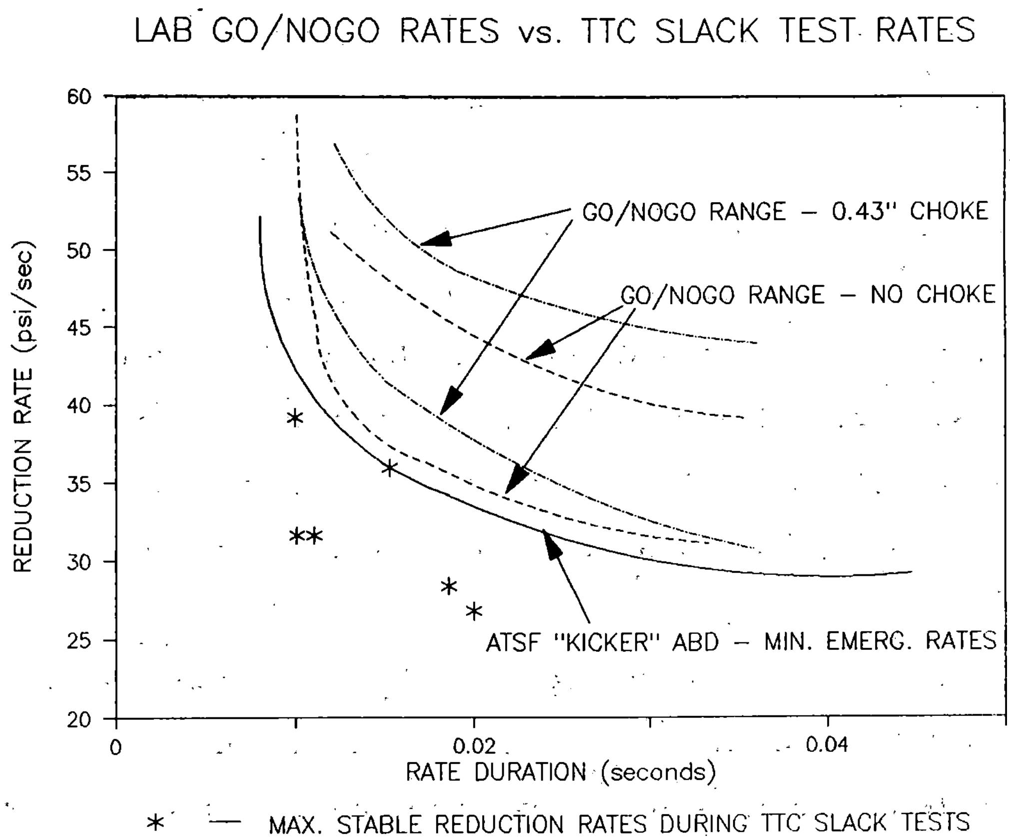


Exhibit 14.10

14.7 EMERGENCY STOP TESTS

Emergency stop tests were made with and without a 0.43 inch dia. choke placed over the center air port between the emergency portion and the pipe bracket. This air passage connects brake pipe pressure from the pipe bracket to the top of the emergency piston. Lab tests mentioned previously have shown that a choke of this size will slightly desensitize a control valve, making it less likely to respond to slack induced pressure pulses.

NYAB had earlier run some tests on 50 cars of their 150 car test rack to determine the effect of a 0.36 inch dia. choke on service and emergency propagation times. The emergency propagation time was 0.5 seconds slower, which might be acceptable in actual train service. However, the propagation time for a minimum service reduction on ABDW control valves was 4.5 seconds slower, which was clearly unacceptable. So it became important to determine what the effect of the larger 0.43 in. dia. choke had on propagation times under actual stop test conditions.

The stop tests were done from 50 mph and 30 mph. Three tests were made from each speed with and without the pipe bracket chokes. The brake applications were made running in a counter clockwise direction at T33 for the 50 mph stops and T31 for the 30 mph stops (see Exhibit 14.3). Stop distances were measured and propagation rates recorded using the PCM instrumentation. The train consist for all stop tests weighed 2872 tons and consisted of three 4-axle locomotives, 32 empty flat cars and four loaded 100 ton hoppers. Exhibit 14.11 gives the test parameters and results from each test, and Exhibit 14.12 is a graphical representation of the results.

Exhibit 14.11

TEST NUMBER	INITIAL SPEED mph	STOP TIME seconds	STOP DIST. feet	0.43 CHOKE USED	EMERGENCY PROPAGATION ft/sec
40	30.4	29.3	839.5	NO	950.00
41	30.4	29.4	820	NO	957.35
42	30.0	29.1	807	NO	954.88
43	50.4	49.1	2290	NO	954.88
44	50.4	48.7	2243	NO	954.88
45	50.7	48.4	2230	NO	952.44
				AVERAGE =	954.07
117	29.7	29.3	807	YES	980.08
118	30.4	29.8	830	YES	982.67
119	30.7	29.5	829	YES	982.67
120	50.8	46.7	2097	YES	982.67
121	50.8	46.5	2090	YES	982.67
122	50.6	48.3	2101	YES	980.08
				AVERAGE =	981.81

The ambient temperature was about 30 deg. F. during the no-choke tests, and 55 deg. F. during the choke tests. When the average propagation rate without chokes is corrected for ambient temperature (see appendix B) the rate is 978.11 ft/sec. When this is compared to the actual measured rate of 981.81 ft/sec with the chokes at 55 deg. F., it can be seen that the chokes of 0.43 inch dia. had no significant effect on emergency propagation times on the 36 car test train. It remained to be seen whether a 0.43 choke would effect service propagation rates on trains equipped entirely with ABDW type valves. This would determine whether the choke would be placed in the pipe bracket filter or in the ABD/ABDW emergency portion top cover. Once this was determined, the next step was field testing of these chokes on selected UDE prone unit trains, such as a CP unit coal train.

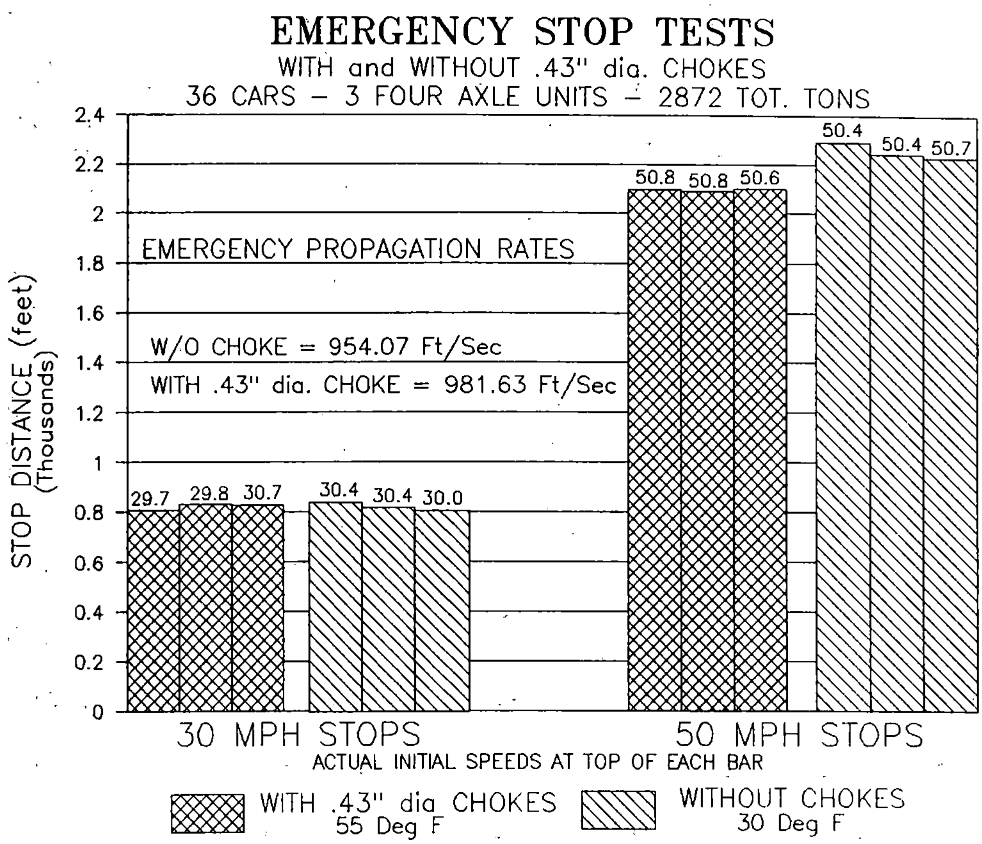


Exhibit 14.12

15.0 CONCLUSIONS

Even though the entire AAR portion of the UDE study is not yet complete, some firm conclusions have been made;

1. Most of those UDE's which are unexplainable are caused by rapid short duration pressure reductions. These reductions are severe enough to cause a control valve in normal operating condition to make an emergency application.
2. These rapid short duration pressure reductions are caused by severe slack action.
3. 0.43 inch diameter chokes located between the pipe bracket and the emergency portion will slightly desensitize a control valve against slack induced pressure pulses. They do not affect service or emergency propagation times on trains primarily equipped with non-AAV type control valves and A-1 reduction relay valves.
4. The spill-over check valve in the ABD/ABDW type control valves are no longer required in today's railroad operating environment, and when defective can cause a control valve to become prone to UDEs. Consideration should be given to removing the spill-over check valve function whenever a control valve is cleaned.
5. Even though the large majority of control valves positively identified as "kickers" in this study were not defective, it is still possible for a control

valve to become defective and cause UDEs. The present AAR Repair Track Air Brake Test is inadequate to find these control valves, particularly for cars with over 75 feet of brake pipe.

6. Seasonal increases in UDE occurrence can be attributed to certain combinations of low ambient temperature and high brake pipe moisture content. On the CP, air driers have sharply reduced seasonal increases of UDEs.

The next step in the AAR UDE study is to verify the performance of the pipe bracket chokes on a 150 car test rack. Testing will address performance under high leakage conditions, the ability to jump four 50 foot long cars with cut-out control valves in the middle of a 150 car train, and the effect on AAV performance on a solid train of ABDW control valves. Once these tests are finished, and the final location of the choke is determined, then enough hardware will be made to conduct in service field tests on the Norfolk Southern and the Canadian Pacific. The service tests will be made on unit trains known to have a high number of UDEs. These trains will be monitored to determine if the chokes do indeed reduce UDEs.

Appendix A

EMERGENCY PROPAGATION RATES AS AFFECTED BY TEMPERATURE

Choke plates of 0.43 inch diameter were installed between the emergency portion and the pipe bracket on all 36 cars except for car 2 (Z1AW) and car 35 (sensitive ABD valve). The chokes had no effect on stop distances or emergency propagation rates. The propagation rates were faster for the tests with the chokes due to the warmer ambient temperature.

The acoustic speed (speed of sound) in free air is;

$$Va = \sqrt{@RT}$$

where

@ = 1.4 = ratio of specific heats
R = 1716.26 ft/sec^2-Deg R = Gas constant for air
T = ambient temperature in Degrees Rankine absolute

The speed of propagation in a pipe is better approximated by;

$$Vp = \sqrt{RT} \quad \text{ft/sec}$$

because the large pressure drop of a brake application tends to lower the temperature of the air in the pipe, reducing the velocity of transmission.

For the TTC tests, the ambient temperatures were;

55 Deg F = 515 Deg R - tests WITH 0.43 inch dia. choke
30 Deg F = 490 Deg R - tests WITHOUT 0.43 inch dia. choke

The ratio of propagation speeds - with chokes / no chokes is;

$$R_{Vp} = \frac{\sqrt{RT}}{\sqrt{RT}} = \frac{\sqrt{1716.26 * 515}}{\sqrt{1716.26 * 490}} = 1.0252$$

The measured propagation rate for the NO CHOKE tests was;

954.07 ft/sec at 30 Deg F

Therefore, the propagation rate which could be expected without chokes at 55 deg F would be;

954.07 * 1.0252 = 978.11 ft/sec

The actual measured propagation rate WITH THE CHOKES at 55 Deg F was;

981.63 ft/sec

So it appears that a 0.43 inch diameter choke between the pipe bracket and the emergency portion has NO SIGNIFICANT EFFECT on emergency propagation times or emergency stopping distances.

Appendix B

TEST LOG OF TTC UDE TEST

12-13-88

COUPLERS ZEROED PRIOR TO FIRST RUN

RUN #	BRAKE APPL. AIR	BRAKE APPL. DYN.	SPEED mph	TRACK MARKER	COMMENTS
1	MIN	2	30	T43	150 K BUFF, RUN-IN VERY LATE
2	MIN	4	30	T43	RUN-IN VERY LATE
3	MIN	4	30	T40	RUN-IN TOO SOON
4	MIN	4	30	T40.5	640 K BUFF ON CAR 22
5	MIN	4	30	T40.1	100 K BUFF ON CAR 22
6	MIN	6	30	T40.1	250 K BUFF, DYN. APPL. LATE
7	MIN	6	30	T40.1	600 K BUFF, APPL. 3 SEC AFTER RUN-IN
8	MIN	8	30	T40.1	500 K BUFF, APPL. 3 SEC AFTER RUN-IN
9	MIN	8	30	T40.1	500 K BUFF, APPL. AND RUN-IN COINCIDE
10	MIN	8	30	T40.1	500 K BUFF, APPL. 1 SEC AFTER RUN-IN
11	MIN	8	30	T40.1	500 K BUFF, APPL. AFTER RUN-IN

12-14-88

COUPLERS ZEROED PRIOR TO FIRST RUN

RUN #	BRAKE APPL. AIR	BRAKE APPL. DYN.	SPEED mph	TRACK MARKER	COMMENTS
12	MIN	6	30	T43	LOCOMOTIVE DATA ONLY, PCM BOMBED
13	MIN	6	30	T43	400 K BUFF, APPL. EARLY
14	MIN	8	30	T43	200 K BUFF, DYN. VERY LATE
15	MIN	8	30	T43	125 K BUFF, NOTHING SIGNIFICANT
16	MIN	8	30	T42	350 K BUFF, DYN. LATE
17	MIN	8	30	T42	350 K BUFF
18	MIN	8	30	T41	500 K BUFF
19	NO	4	30	T13.5	ACCELERATED HARD TO FOOT OF GRADE, WENT INTO DYNAMIC 4, 600 K BUFF
20	MIN	8	30	T40.1	600 K BUFF, DYN APPL 3 SEC LATE
21	NO	5	30	T13	ACCELERATED HARD TO FOOT OF GRADE, WENT INTO DYNAMIC 4, 750 K BUFF PRESSURE PULSES IN BRAKE PIPE
22	MIN	8	30	T40.1	450 K BUFF, PRESSURE PULSES IN BP
23	MIN	4	30	T13	ACCELERATED HARD TO FOOT OF GRADE, AIR + DYN APPL, 650 K BUFF AIR APPL 6 SEC LATE
24	15	NO	30	T42	PULLED HARD TO T42, WIPE THROTTLE FROM 8 TO IDLE, MADE 15 PSI REDUCTION, 500 K BUFF

25	20	NO	30	T41	PULLED HARD TO T41, WIPE THROTTLE FROM 8 TO IDLE, MADE 20 PSI REDUCTION, 500 K BUFF
26	MIN	4	30	T13	MIN APPL WHEN DYN AMP = 350, 400 K BUFF, APPL LATE
27	MIN	4	30	T14	MIN APPL WHEN DYN AMP = 200, 500 K BUFF, GOOD APPL
28	MIN	5	30	T14	MIN APPL WHEN DYN AMP = 200, 650 K BUFF, GOOD APPL

12-15-88 SNOWING, 10 Deg F.

COUPLERS ZEROED PRIOR TO FIRST RUN

RUN #	BRAKE APPL. AIR	DYN.	SPEED mph	TRACK MARKER	COMMENTS
29	MIN	5	30	T14	MIN APPL WHEN DYN AMP = 200, 450 K BUFF
30	MIN	6	30	T14	MIN APPL WHEN DYN AMP = 250, 450 K BUFF. GOOD PULSE FROM CAR 30 TO BACK OF TRAIN, THEN REFLECTED FORWARD TO CAR 22
31	MIN	7	30	T14	MIN APPL WHEN DYN AMP = 250, 500 K BUFF
32	MIN	8	30	T14	MIN APPL WHEN DYN AMP = 250, 650 K BUFF, 10PSI/SEC RATE ON LAST CAR
33	MIN	8	30	T14	MIN APPL WHEN DYN AMP = 250, 650 K BUFF, 1.75 PSI REDUCTION ON LAST CAR
34	MIN	8	30	T14	MIN APPL WHEN DYN AMP = 300, 600 K BUFF, 1.75 PSI REDUCTION ON LAST CAR

12-16-88 CLEAR, 15 Deg F.

ZEROED COUPLERS 9:30 A

RUN #	BRAKE APPL. AIR	DYN.	SPEED mph	TRACK MARKER	COMMENTS
35	MIN	6	30	T14	MIN APPL WHEN DYN AMP = 250, 400 K PEAK BUFF, 250 K SUSTAINED BUFF
36	MIN	8	30	T14	MIN APPL WHEN DYN AMP = 250, 550 K PEAK, 250 K SUSTAINED BUFF QUICK SERVICE ON LAST CAR STARTED PULSE MOVING FORWARD TO CAR 12
37	MIN	8	30	T13	MIN APPL WHEN DYN AMP = 250, 250 K PEAK

38	12	8	30	T14	12 psi APPL WHEN DYN AMP = 250, 650 K PEAK. LITTLE SLACK AT HEAD END. PULSE ON CAR 22. NO DYNAMIC ON FIRST TWO (2) UNITS
39	20	----	30	T14	PULLED HARD TO T14, WIPE THROTTLE FROM 8 TO IDLE, SMALL PULSE MOVED FORWARD FROM CAR 36 DUE TO RUN-IN.
40	EM	----	30	T31	-----------------------------------
41	EM	----	30	T31	STOPS 41 - 45 WERE EMERGENCY
42	EM	----	30	T31	APPLICATIONS WITHOUT PIPE BRACKET
43	EM	----	50	T33	CHOKES. LOCOMOTIVES WERE BAILED
44	EM	----	50	T33	OFF. 36 CARS TOTAL (NO HAMMERS)
45	EM	----	50	T33	-----------------------------------

Test runs 46 through 116 validation runs for the TOES computer model. These tests were not part of the UDE study.

==

1-4-89 CLEAR, 50 Deg F.

ZEROED COUPLERS PRIOR TO TESTING. PIPE BRACKET CHOKES INSTALLED ON ALL CARS EXCEPT CAR 2 AND CAR 35. CAR 35 HAS ATSF "KICKER" ABD WITH BP, BC, AND VENT VALVE PISTON PRESSURE TRANSDUCERS INSTALLED.

RUN #	BRAKE AIR	APPL. DYN.	SPEED mph	TRACK MARKER	COMMENTS
117	EM	----	30	T31	-----------------------------------
118	EM	----	30	T31	STOPS 117 - 122 WERE EMERGENCY
119	EM	----	30	T31	APPLICATIONS WITH PIPE BRACKET
120	EM	----	50	T33	CHOKES. LOCOMOTIVES WERE BAILED
121	EM	----	50	T33	OFF. 36 CARS TOTAL (NO HAMMERS)
122	EM	----	50	T33	-----------------------------------
123	MIN	8	30	T14	MIN APPL WHEN DYN AMP = 250,
124	MIN	8	30	T14.5	MIN APPL WHEN DYN AMP = 250,
125	MIN	8	30	T14.5	MIN APPL WHEN DYN AMP = 250, APPL WAS 6 SECONDS LATER THAT RUN 124
126	MIN	8	30	T14.5	MIN APPL SIMULTANEOUSLY WITH MAX DYN APPLICATION
127	MIN	8	30	T14.5	MIN APPL 9 SECONDS AFTER MAX DYN APPLICATION
128	MIN	INDP	30	T35 *	MIN AND INDEPENDENT SET SIMULTANEOUSLY AT FOOT OF GRADE
129	MIN	INDP	30	T35 *	MIN SET 9 SECONDS AFTER IND BRAKE AT FOOT OF GRADE
130	MIN	INDP	30	T35 *	MIN SET 6 SECONDS AFTER IND BRAKE AT FOOT OF GRADE
131	MIN	INDP	20	T35 *	MIN SET 6 SECONDS AFTER IND BRAKE AT FOOT OF GRADE
132	MIN	INDP	10	T35 *	MIN SET 6 SECONDS AFTER IND BRAKE AT FOOT OF GRADE

133	MIN	NO	0	T35	POWER ADVANCED TO RUN 8, THEN MIN APPLICATION WAS MADE AS UNITS BEGAN TO MOVE. UNITS BACKED INTO TRAIN WITH SLACK INITIALLY STRETCHED.
134	MIN	NO	0	T35	SAME AS RUN #133 EXCEPT MIN APPL. 5 SEC. AFTER UNITS BEGAN TO MOVE
135	MIN	NO	0	T35	REPEAT OF RUN # 134
136	MIN	NO	0	T35	SAME AS RUN #134 EXCEPT MIN APPL. 3.5 SEC. AFTER UNITS BEGAN TO MOVE
137	MIN	NO	0	T35	SAME AS RUN #134 EXCEPT MIN APPL. 2.5 SEC. AFTER UNITS BEGAN TO MOVE
138	MIN	NO	0	T35	SAME AS RUN #137
139	MIN	NO	0	T35	SAME AS RUN #138 EXCEPT MIN APPL. 5.5 SEC. AFTER UNITS BEGAN TO MOVE
140	MIN	NO	0	T35	SAME AS RUN #139 EXCEPT MIN APPL. 4.5 SEC. AFTER UNITS BEGAN TO MOVE
141	MIN	NO	0	T35	SAME AS RUN #139
142	MIN	NO	0	T35	SAME AS RUN #139
143	MIN	NO	0	T35	SAME AS RUN #139

1-5-89 CLEAR, 44 Deg F.

ZEROED COUPLERS PRIOR TO TESTING. PIPE BRACKET CHOKES INSTALLED ON ALL CARS EXCEPT CAR 2 AND CAR 35. CAR 35 HAS ATSF "KICKER" ABD WITH BP, BC, AND VENT VALVE PISTON PRESSURE TRANSDUCERS INSTALLED.

RUN	BRAKE APPL.		SPEED	TRACK	
#	AIR	DYN.	mph	MARKER	COMMENTS
144	F.S.	NO	39.9	T33	FULL SERVICE STOP TESTS - 2405 ft.
145	F.S.	NO	39.3	T33	FULL SERVICE STOP TESTS - 2388 ft.
146	F.S.	NO	30.1	T33	FULL SERVICE STOP TESTS - 1692 ft.
147	F.S.	NO	26.8	T33	FULL SERVICE STOP TESTS - 1469 ft.
148	F.S.	NO	20.6	T33	FULL SERVICE STOP TESTS - 1005 ft.
149	F.S.	NO	20.2	T33	FULL SERVICE STOP TESTS - 956 ft.
150	F.S.	NO	10.7	T33	FULL SERVICE STOP TESTS - 408 ft.
151	F.S.	NO	10.9	T33	FULL SERVICE STOP TESTS - 378 ft.

THE FOUR LOADED HOPPERS CARRYING THE DYNAMOMETER COUPLERS WERE SET OUT OF THE TRAIN. NOW HAD 32 CARS TOTAL. CAR 32 HAS ATSF "KICKER" ABD WITH BP, BC, AND VENT VALVE PISTON PRESSURE TRANSDUCERS INSTALLED.

152	MIN	NO	0	T35	POWER ADVANCED TO RUN 8, THEN MIN APPLICATION WAS MADE 4.5 SEC. AFTER UNITS BEGAN TO MOVE. UNITS BACKED INTO TRAIN WITH SLACK INITIALLY STRETCHED. NOT VERY GOOD SLACK ACTION.

153	MIN	NO	0	T35	INDEPENDENT FULLY APPLIED, POWER ADVANCED TO RUN 8, THEN INDEPENDENT WAS RELEASED AS UNITS BEGAN TO MOVE. MIN APPLICATION WAS MADE 4.5 SEC. AFTER UNITS BEGAN TO MOVE. UNITS BACKED INTO TRAIN WITH SLACK INITIALLY STRETCHED. NOT VERY GOOD SLACK ACTION.
154	MIN	NO	0	T35	SAME AS RUN #153 EXCEPT MIN APPL. 3 SEC. AFTER INDEPENDENT RELEASE
155	MIN	NO	0	T35	SAME AS RUN #154 EXCEPT MIN APPL. 2 SEC. AFTER INDEPENDENT RELEASE INDEPENDENT B.C. PRESSURE WAS INCREASED TO 62 PSI
156	MIN	NO	0	T35	SAME AS RUN #155. INDEPENDENT B.C. PRESSURE WAS INCREASED TO 62 PSI
157	MIN	NO	0	T35	SAME AS RUN #156. INDEPENDENT B.C. PRESSURE WAS INCREASED TO 86 PSI
158	MIN	NO	0	T35	SAME AS RUN #157 EXCEPT MIN APPL. 3 SEC. AFTER INDEPENDENT RELEASE
159	MIN	NO	0	T35	SAME AS RUN #158 EXCEPT MIN APPL. 2 SEC. AFTER INDEPENDENT RELEASE
160	MIN	NO	0	T35	SAME AS RUN #159

Tests 161 - 164 were independent release tests for TOES

1-6-89

PIPE BRACKET CHOKES INSTALLED ON ALL CARS EXCEPT CAR 2 AND CAR 35. CAR 35 HAS ATSF "KICKER" ABD WITH BP, BC, AND VENT VALVE PISTON PRESSURE TRANSDUCERS INSTALLED. ALL OF THE FOLLOWING TESTS WERE MADE WITH THE FRONT 22 CARS STRETCHED, AND THE LAST 10 CARS BUNCHED. INDEPENDENT WAS APPLIED AT 86 psi B.C. PRESSURE, THROTTLE ADVANCED TO RUN 8, THEN INDEPENDENT WAS RELEASED AS UNITS BEGAN TO MOVE.

RUN #	BRAKE APPL. AIR	BRAKE APPL. DYN.	SPEED mph	TRACK MARKER	COMMENTS
165	MIN	NO	0	T35	MINIMUM APPLICATION 2 SEC. AFTER INDEPENDENT RELEASE
166	MIN	NO	0	T35	SAME AS RUN #165, EXCEPT HAND BRAKE APPLIED ON CAR 22 AND LAST CAR
167	MIN	NO	0	T35	SAME AS RUN #166, EXCEPT MINIMUM APPLICATION WAS TOO LATE
168	MIN	NO	0	T35	SAME AS RUN #166. BEST PIPE PULSE SO FAR
169	MIN	NO	0	T35	SAME AS RUN #168. EXCEPT MINIMUM APPLICATION WAS TOO LATE
170	MIN	NO	0	T35	SAME AS RUN #168. PULSE ALMOST AS GOOD AS RUN #168.

Test was concluded at this point.

Appendix C

Brake System Computer Model

University of New Hampshire

Prof D. E. Limbert

INFLUENCE OF FREIGHT CAR MOTION
ON THE OPERATION OF TRAIN BRAKING SYSTEMS

Michael H. de Leon
David E. Limbert
University of New Hampshire

September 9, 1988

ABSTRACT

A computer model has been developed which adds to an existing simulation program the capability of studying the effect of train car motion on the performance of pneumatic braking systems. This paper gives an overview of the model and highlights simulation results, with particular emphasis on undesired braking operations. The simulations show that certain train car motions can induce significant pressure variations in the main brake line (brake pipe), and in some cases, the car mounted ABDW brake control valves respond to these pressure variations by activating car brakes.

I. INTRODUCTION

A growing concern within the railroad industry is that of undesired braking operations occurring spontaneously on freight trains.[1] Several physical mechanisms are suspected to be contributing to the problem. One is that the brake pipe—a long fluid transmission line running the entire length of the train—is affected by car motion, resulting in fluctuations in the pressure of the air within the pipe. Another is that the brake pipe is a lightly damped system which may promote undesirable flow/pressure oscillations. A third concern is that the cars' brake valves may be marginally stable at certain operating points, and dynamic interaction with the brake pipe may cause them to go into an unwanted emergency mode.

Braking operations on freight trains can be simulated using currently available models. These existing simulators, however, are unable to predict anomalous transient behavior because they were designed primarily to study steady-state pressure distributions within the brake pipe, operating points in car valves and reservoirs, controlled braking operations, and system recharge modes. The study of undesired braking behavior, on the other hand, requires that the model take into account pipe accelerations, fast transients, and the effect of higher-order energy storage terms (e.g., piston masses and cavity capacitances in car valves, heat transfer and storage, branch pipe dynamics, and time-varying brake pipe geometries). The goal of the current research is to develop a much more accurate model of the brake pipe, called a micro-model, which is capable of simulating fast transients and other phenomena.

Although the micro-model is presently under development, the first phase of the research has produced important results. UNH has successfully modeled the dynamic behavior of air in a moving brake pipe, and simulations verify that certain car motions can induce pressure fluctuations in the brake pipe which are large enough to trigger undesired braking operations.

II. PHYSICAL BASIS FOR THE MODEL

The simulation model which incorporates train motion is called MOVPIPE. It is essentially an addition to an existing model called PIPE [2]. PIPE had not allowed researchers to study the effect of train motion on the brake pipe, since it was designed under the assumption that pipe accelerations do not contribute significantly to changes in flow. The motivation for adding car velocity to the model arose from observations of pressure fluctuations in the brake pipe coinciding with train acceleration during field tests. These acceleration-induced pressure variations are suspected to cause or influence valve operations. A cursory analysis (presented below) shows that a whole train acceleration or deceleration of 0.1g could generate a tail end pressure variation of 1.86 psi relative to a non-accelerating pipe (with a head-end pressure of 91 psig, and 5000-ft length), after steady-state is achieved.

The physical basis for acceleration-induced pressure fluctuations in a pipe is similar to that of coffee sloshing in a cup. Observing a cup full of coffee sitting on the dashboard of a rapidly accelerating automobile (in this case the term "acceleration" is used generally, and means a time change of velocity in any direction), one would notice that the acceleration causes the coffee to slosh in the cup. This is because the mass of the coffee tends to oppose changes in its velocity, according to Newton's Second Law. The coffee tends to remain fixed in space, even as the cup is accelerated away from its initial position. Disregarding the spilled beverage which might result, most of the coffee is forced to accelerate at the same rate as the cup. Its acceleration is achieved through a pressure buildup in the fluid at the "back" side of the cup, which can be observed as a swelling of the free surface [3].

In a train brake pipe, the air mass is affected by the same physical laws. Consider a closed-ended pipe of length L as shown in Figure 1(a). The entire pipe is subjected to a constant acceleration $\bar{a}$ to the left. The inertia of the air in the pipe tends to resist changes in its velocity, so the air begins to accumulate at the right-hand end. Since that end is closed, the pressure there rises, forcing the air to the left of it to accelerate.

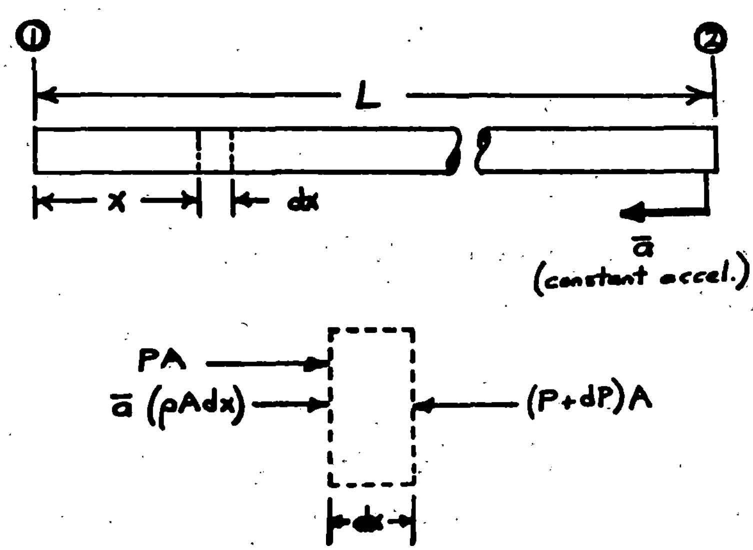


Figure 1

(a): Accelerating closed ended pipe.

(b): Differential control volume.

The easiest way to analyze the response is to draw a control volume of a differential piece of the pipe, dx, shown in Figure 1(b), and apply the law of conservation of linear momentum. Assuming that the air has reached some steady-state pressure distribution and has stopped flowing relative to the pipe wall, the pressure forces acting on the control volume are as shown. The air in the control volume accelerates in response to the applied forces. In fact, when steady-state is reached in the closed-ended pipe, the acceleration of the air in the pipe matches that of the pipe, $\bar{a}$. Conservation of momentum applied to the differential piece of pipe yields:

$$pA + \bar{a}(\rho A dx) = (p + dp)A$$

where ρ = the mass density of air in the control volume,
and A = the cross-sectional area of the pipe.

Using the ideal gas law to replace ρ with a function of temperature and pressure, followed by rearranging, gives:

$$\frac{\bar{a}p}{RT}dx = dp.$$

The differential relationship here is integrated between both ends of the pipe (assuming constant temperature), giving the relationship between pipe air pressure and position along the pipe:

$$\frac{\bar{a}}{RT}\int_0^L dx = \int_{p_1}^{p_2} \frac{dp}{p}.$$

Evaluating the integrals leads to an expression for the pressure difference from one end of the pipe to the other:

$$\Delta p = p_2 - p_1 = p_1\left(e^{\bar{a}L/RT} - 1\right).$$

For example: if the pressure at the left-hand end of a 5000-ft. pipe (p_1) were maintained at 105.8 psia via the action of a regulating valve, and if $\bar{a} = -0.1\ g = -3.22$ ft/sec^2, the pressure difference between points 1 and 2 would be $\Delta p = -1.855$ psi, assuming the air is at 70°F.

III. OVERVIEW OF MOVPIPE

The computer model is created by performing control-volume analyses on discrete pipe sections, applying the conservation laws of fluid mechanics (continuity of mass and conservation of linear momentum), and writing the governing differential equations for the pipe flow [3]. Since the flow is assumed to be isothermal, the energy equation is not used. The equation of state for air is based on the ideal gas law, $P = \rho RT$. The numerical method which calculates the time derivatives is selected by considering its accuracy, efficiency, and stability. The choice of numerical method determines how the time variables are made discrete. It is necessary that equations handle only discrete quantities, since digital computers are capable of using only these kinds of data. In the case of MOVPIPE, a so-called semi-implicit numerical scheme is used. The semi-implicit method is relatively stable and accurate, and is quite efficient computationally.

The MOVPIPE model differs from PIPE in its representation of absolute flow velocities. The absolute velocity of the air in the brake pipe is now given by

$$V_{abs} = u - V_p,$$

where u = velocity of pipe air relative to the pipe, assigned as positive toward the rear of the train;

V_p = absolute velocity of the brake pipe, taken as positive in the direction of forward motion.

This difference affects the momentum equation in the model.

IV. SIMULATION OF CAR VELOCITY

It is necessary to have a means by which to generate simulated values for pipe velocity, V_p. The approach used here is to generate velocity terms independent of whatever braking operations are being simulated. While this approach does not reflect the real world, it does permit studying the effect of pipe motion on the simulation results. It also does not preclude the incorporation of a more complete, closed-loop train motion simulator. The program is designed with this approach in mind—it allows the future addition of other, alternative pipe velocity simulators.

Pipe velocity terms are generated by a subroutine in MOVPIPE called PIPEVEL1. This subroutine is an open loop velocity simulator which computes car (and pipe) velocities by integrating on an acceleration schedule specified by the user. Neither car masses and their dynamic interactions nor the retarding effect of simulated brake operations are involved; hence the open loop designation. The train acceleration is read from an input file called TRAINDYN.DAT, a schedule of up to 30 rectangular acceleration intervals defined by TS1(K), TF1(K), and ACCEL(K)—the start time of the Kth interval, the finish time, and the value in feet/second^2, respectively. Figure 2 gives a graphical example of an acceleration schedule. An integration in time of the profile yields car velocity.

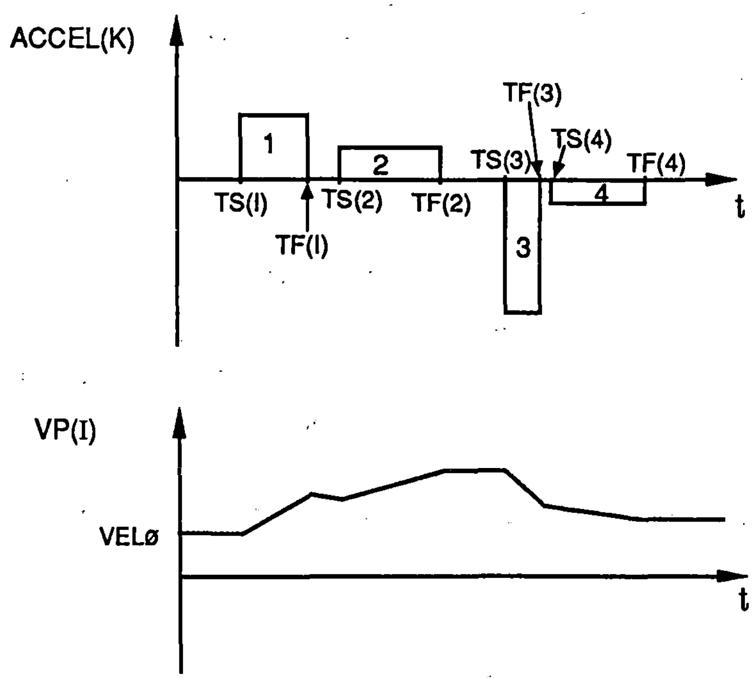


Figure 2. Top: The commanded acceleration schedule.
Bottom: The resulting car velocity.

It is desirable to include a simulation of car "stack-up" or run-in, because of the potentially large acceleration impulses associated with this phenomenon. Run-in is a result of decelerating a train of cars linked by couplings with slack in them. Initial transfer of momentum between cars having free play can be a very abrupt process. The momentary "bump" that the cars experience may approach 2 g (64 ft/sec^2) or more.

Car run-in is specified by which cars (pipe sections) are to experience a deceleration. The first car specified is N1ST, and the last car in the train to undergo the acceleration is NLST. Only the cars between and including these two cars are subjected to the acceleration commands. The stack-up delay (TSLACK) is also supplied by TRAINDYN.DAT. An example of TRAINDYN.DAT is given in Figure 3. In this example, the first two lines indicate that run-in and any subsequent accelerations are to occur between pipe sections 50 and 60. The third line gives the delay between successive car collisions, and the fourth line specifies the initial train velocity. The total number of acceleration intervals that these cars are to experience is given in line 5.

```
50          :N1ST      = First car in train to be accelerated
60          :NLST      = Last car in train to be accelerated
0.044       :TSLACK    = Time (sec) between successive collisions
50.0        :VELO      = Initial train velocity (ft/sec)
2           :NACCEL    = Number of acceleration intervals
-130.0      :ACCEL(K)  = Kth accel value (ft/sec**2) } repeat this
8.00        :TS1(K)    = Kth accel start time (sec)  } pattern for each
8.12        :TF1(K)    = Kth accel finish time (sec) } acceleration inter-
-3.22                                                    val up to NACCEL
8.12
10.00
```

(This is a reference for TRAINDYN.DAT)

Figure 3: Example Input File.

As mentioned previously, a more complete train dynamics model could be incorporated. This model might include the dynamic equations representing momentum transfer between cars, tractive effort by locomotives, braking action of individual cars, coupling elastic behavior, etc. It might also include the effects of uncontrolled inputs such as track grade, windage forces, and wheel/track friction. The simulated car velocities generated by models such as TOS or TOES [5] could be used as input to MOVPIPE.

V. SIMULATION RESULTS

The first simulation run, Figure 4, reflects the hypothetical steady pipe acceleration that was given as an example in Section II. The MOVPIPE model was modified slightly to remove the leakage and branch line effects on the computation. The figure shows a final value of -1.860 psi between the two ends of the pipe, which closely matches the value of -1.855 obtained in the example.

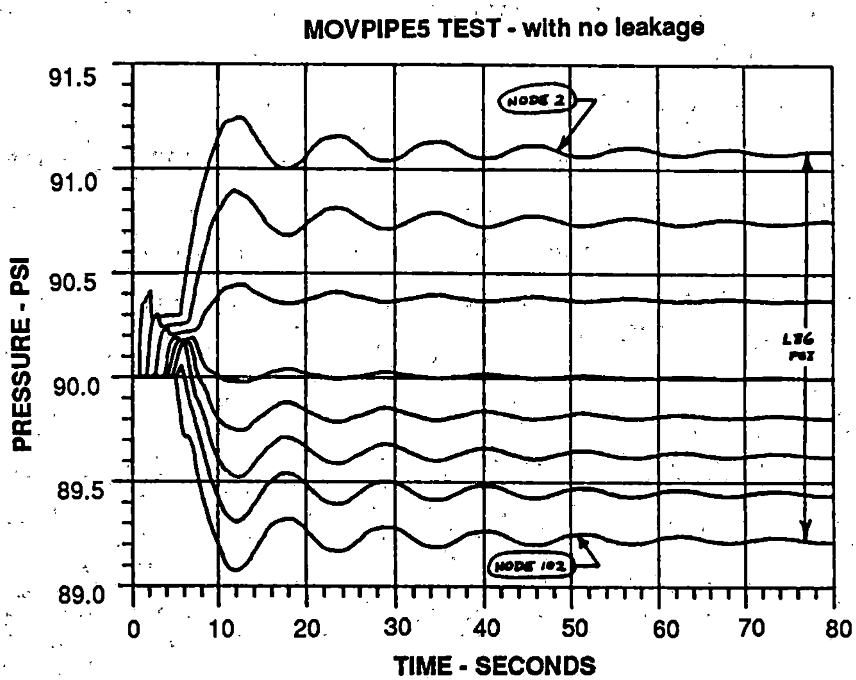
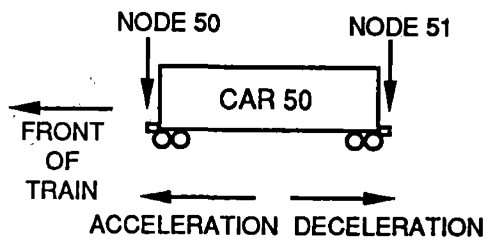


Figure 4: Brake Pipe Pressure for Steady Acceleration.

The second simulation shows how the acceleration of one 50-ft. car (pipe section), in the middle of a 101-car train, produces a pressure pulse in the brake pipe at that car. Figure 5(a) shows a diagram of this car and the variables of interest. Since the car is located mid-train, the ends of its pipe section are unblocked. How may an unblocked tube cause longitudinal acceleration of the air within? If the pipe has a frictional flow characteristic, the initial longitudinal pipe acceleration will give rise to relative motion between the pipe and its interior air. The relative flow causes a pressure drop in the direction of the flow, thereby satisfying the conservation laws. The pressure drop forces the air to accelerate in the direction of the pipe. Eventually the relative velocity between the air and the pipe wall is reduced by friction. A momentary deceleration of a single car at t = 8.00 sec produces a pressure drop in the brake pipe at the rear of the car, and a simultaneous rise at the front, as shown in Figure 5(b). These induced pressure pulses then travel away from their points of origin at roughly the speed of sound. Figure 6 shows the pressure of nodes[1] 46 through 55, with 50 and 51 representing the source points. Notice how the pulse damps out as it travels away from the sources (nodes 50 and 51).



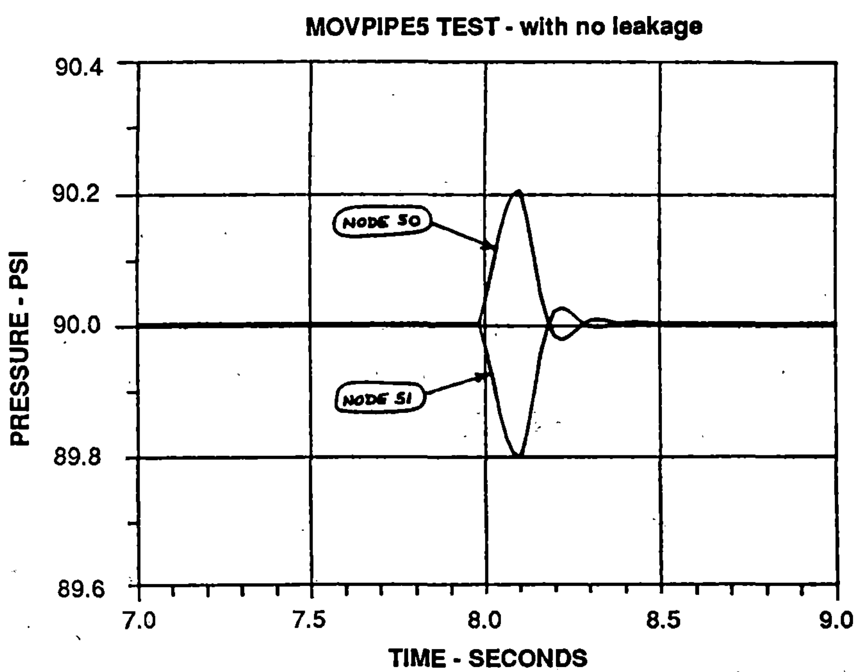


Figure 5 (b): Resulting Brake Pipe Pressure

[1] A node designates a point in the brake pipe between two cars. The node numbering starts with 1 at the front of the train.

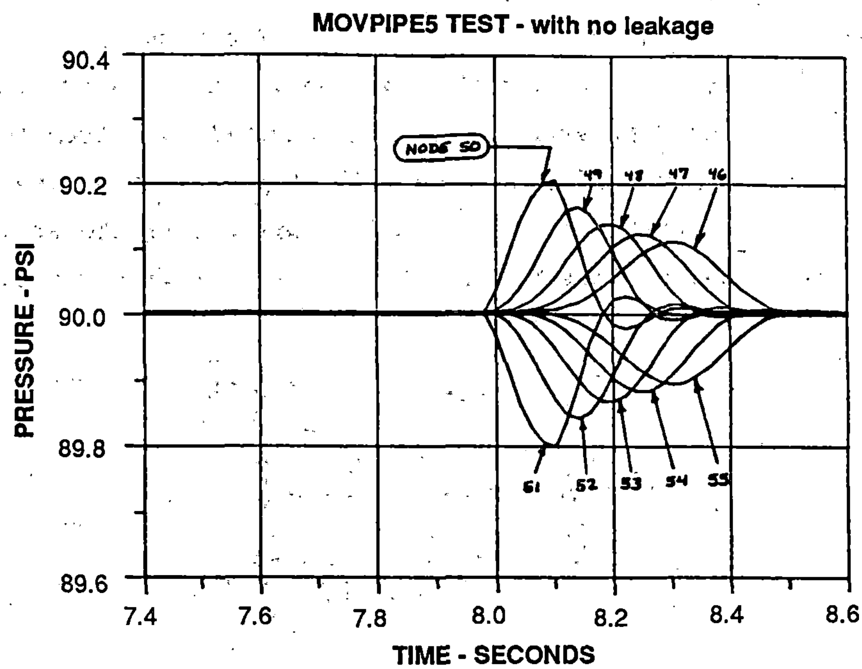


Figure 6: Decaying Brake Pipe Pressures.

One question that arises is whether pulses generated from one car can constructively interfere with (superimpose on) those of another car. For instance, one might expect that if a car were momentarily decelerated, its rear end pressure pulse would travel down the pipe to the car behind it at the speed of sound. Figure 6 shows this as the negative pulse arriving at node 52 at approximately t = 8.05 sec. Now, if the pulse were to arrive at the second car at the same time that the car decelerates, the pressure pulse induced in the second car would superimpose on that of the first. The result would be an increase in the total pulse strength. If this process were allowed to continue, that is, if the cars were successively decelerated at the same rate as the pulses were propagated toward the rear of the train, the pulses could build up to an appreciable magnitude.

The MOVPIPE model confirms that indeed this phenomenon is possible. Figure 7 shows the sequence of pulse superposition resulting from run-in of a series of 50-ft train cars at the rate of 1130 fps, the speed of sound in air at 70°F. Notice that the pulse strength gradually builds up between node 4 and node 18, after which successive collisions and their associated pulses can no longer strengthen because of the increasing frictional damping. In a sense, the pulse has reached its "terminal velocity". In this run, the -4 g run-in bump is followed by a -.1 g steady deceleration.

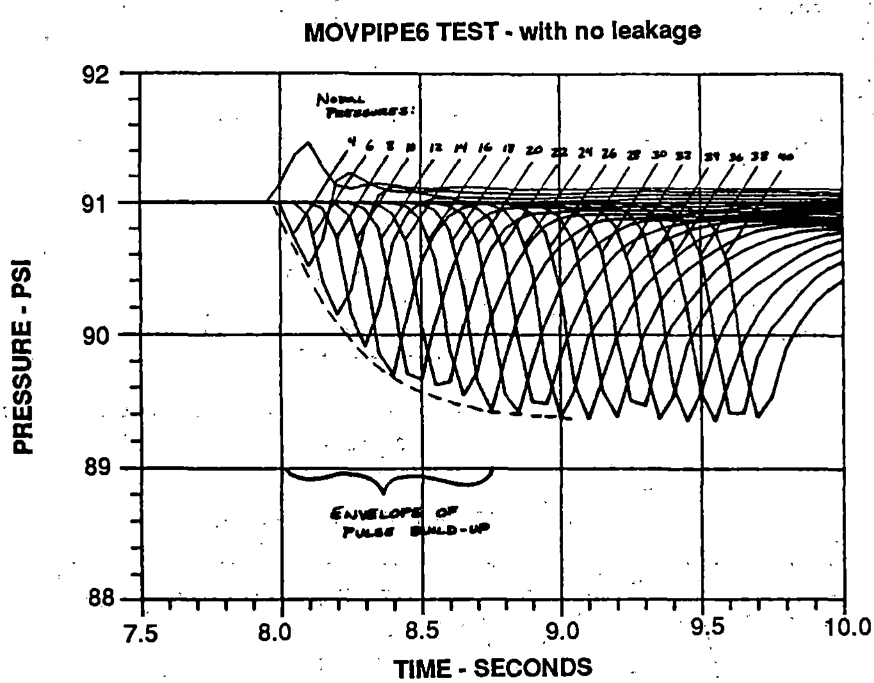


Figure 7: Brake Pipe Pressure Build-Up from Run-in.

To assess how the single-car pulse varies with the car's acceleration and duration, several simulations were made of car 50 (of a 101-car train) undergoing momentary deceleration. Figure 8 shows several curves of brake pipe pressure at node 50 and node 51. In this plot, the deceleration magnitude is the parameter, while the duration of the acceleration is held at a constant 0.12 sec. It is important to note that the time rate of pressure change increases as the magnitude of car acceleration increases. Figure 9 is a plot of brake pipe pressure at nodes 50 and 51. This time the acceleration is held constant in magnitude (-30.0 ft/sec^2), but the time duration of the acceleration impulse is varied from 0.12 sec to 0.60 sec. Durations greater than 0.12 sec do not affect the pulse magnitude for this level of acceleration.

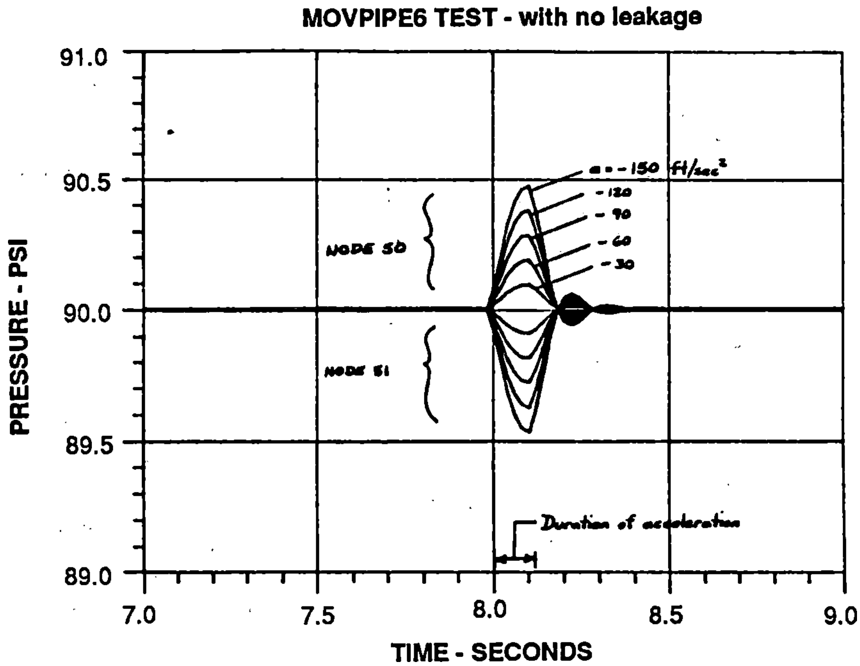


Figure 8: Brake Pipe Pressure, Single Car Accelerations, Varying Magnitude.

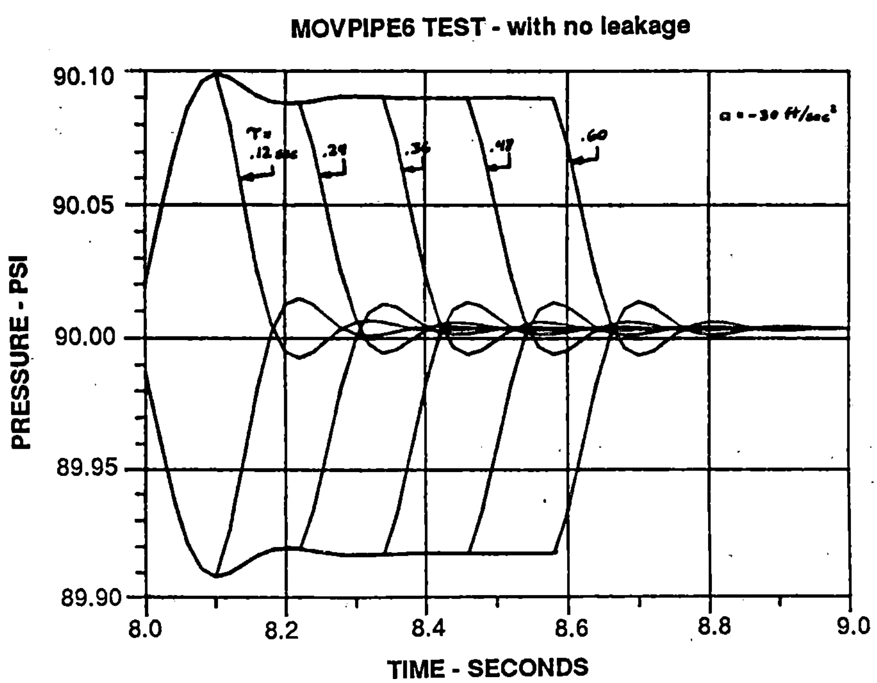


Figure 9: Pipe Pressure, Single Car Accelerations, Varying Duration.

What other mechanisms could generate significant pressure pulses? Perhaps the most important is reflection. The simulations which first revealed undesired braking responses showed that the rear cars of a train go into an undesired emergency (UDE) or service (UDS) application before the cars ahead of them. Examination of the brake pipe pressure curves created by the simulation confirms what is known from theoretical acoustics—that a wave in a fluid will tend to grow in magnitude as it reflects from a rigid boundary. Figure 10 shows brake pipe pressure at even numbered nodes between 84 and 102 (the very end of the train). The pulse steepening is felt everywhere between nodes 98 and 102, and is most pronounced at 102. To understand how this phenomenon is possible, refer to Figure 11. During reflection, part of the reflected pressure pulse is superimposed on the incident pulse. This produces a shorter, taller pulse in the vicinity of the closed end. After reflection, the pulse returns to its former size and shape (neglecting frictional effects) [4].

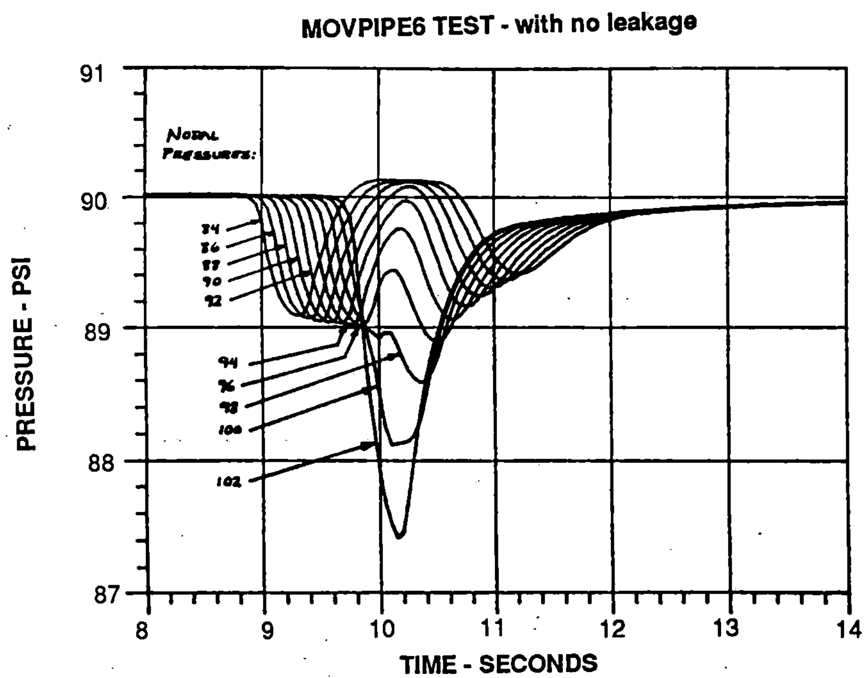


Figure 10: Simulated Pipe Pressure Reflection.

It is possible for a pulse to reflect at the head end of the train, where a 26C valve is located. However, the pulse-steepening effect is much weaker for two reasons. The first is that the valve does not act like a rigid fluid boundary, so a significant portion of the wave energy is transmitted past the valve. The second is that the 26C is a closed-loop pressure regulator which responds to an extraneous pressure fluctuation by attempting to attenuate the disturbance. Therefore, it is much less likely that pulse steepening will be of concern at the head end.

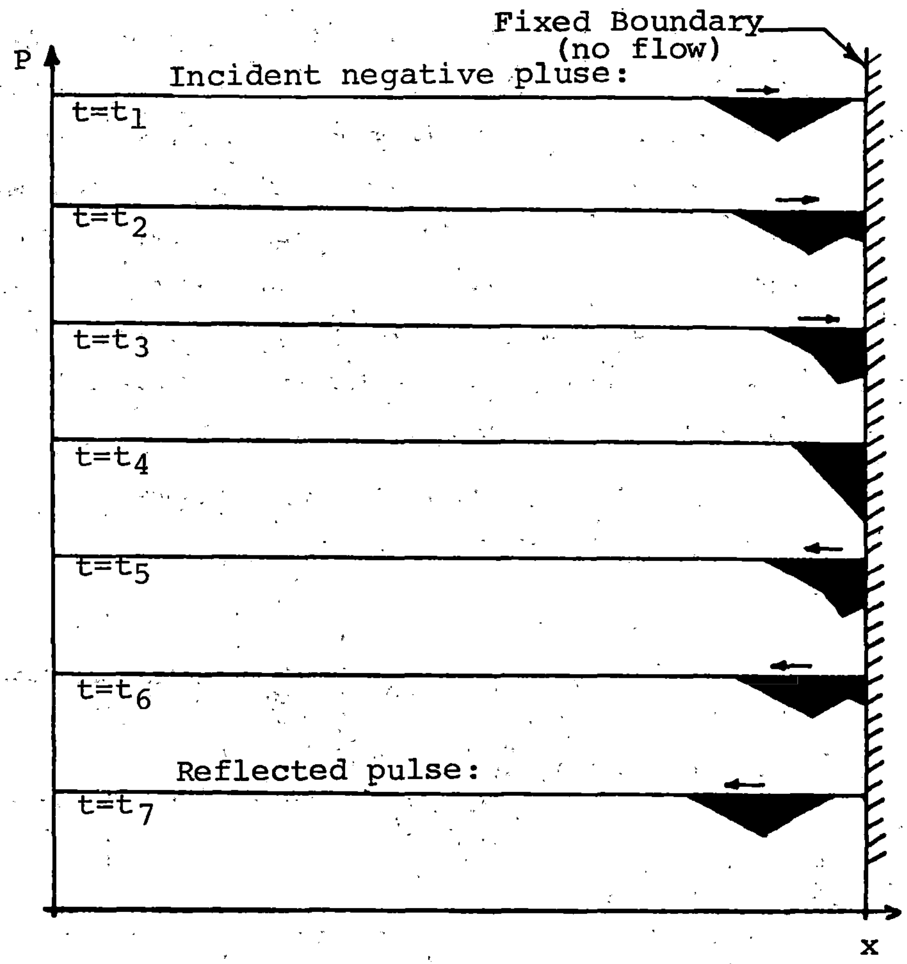


Figure 11: Pressure Increase Due to Pulse Reflection

VI. SIMULATION OF UNDESIRED BRAKING OPERATION

Now attention is turned to simulating undesired braking operations. The table below gives a description of various pipe acceleration scenarios and points to their respective simulation results. The train being simulated has 50-ft cars each equipped with a single ABDW control valve. Each acceleration starts at t = 8.00 sec. In the

Figures referenced below, PBP refers to the gauge pressure at the brake pipe nodes shown. PBCYL refers to the brake cylinder pressures at the indicated cars.

Trial Data:

trial number	1	2	3	4	5	6
total number of cars	102	102	102	101	101	101
cars subject to acceleration	80-102	50-70	40-60	1-101	80-101	50-70
acceleration (ft/sec^2) . . .	-20.0	-24.0	-64.4	-140.0	-64.4	-130.0
duration of accel. (sec) . .	0.40	0.40	0.40	0.30	0.12	0.12
run-in delay (sec)	0.044	0.044	0.044	0.0	0.044	0.044
speed of slack wave (ft/sec)	1130	1130	1130	∞	1130	1130
Figures: PBP/PBCYL	12/13	14/15	16/17	18/	19/	20/

In Figure 12, a service application results from run-in occurring in the last 23 cars of a 102-car train. The run-in deceleration impulse is 2/3 g for 0.4 sec. Reflection of the induced pulse is evident at the end of the train (node 103). The steep pulse causes the last car valve to go into a service mode, and the pipe pressure is being pulled down (probably by the accelerated application valve) enough to cause service applications in other valves toward the front of the train. Corresponding brake cylinder pressures are shown in Figure 13.

Figures 14 and 15 show brake pipe and brake cylinder pressures during run-in of cars 50-70 of the same train. These cars experience deceleration impulses of 3/4 g for 0.4 sec. Notice that the last car goes into service mode first. This occurs because the pulses induced mid-train are not of sufficient strength to trip valves there. Instead, the aggregate pulse travels down the brake pipe toward the rear end. Upon encountering the closed end, it reflects and momentarily steepens. The slew rate of the pulse becomes high enough to precipitate a UDS at the rear car first.

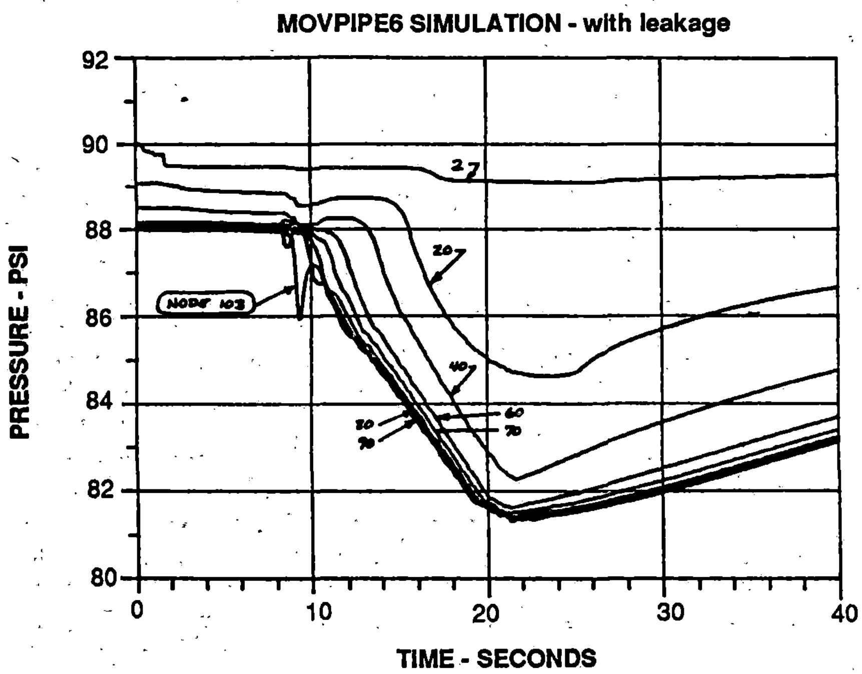


Figure 12: Pipe Pressure During Undesired Service Application.

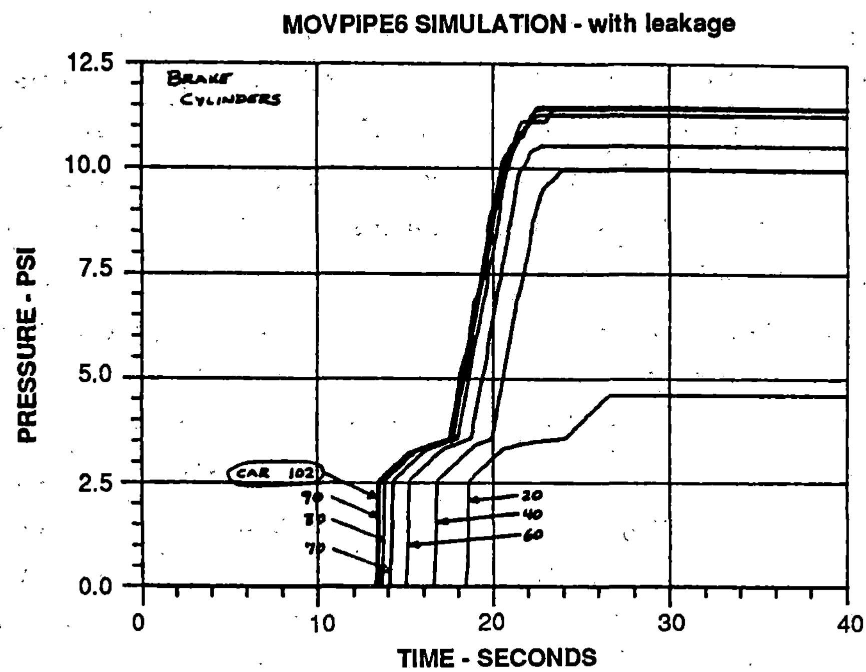


Figure 13: Brake Cylinder Pressure During UDS.

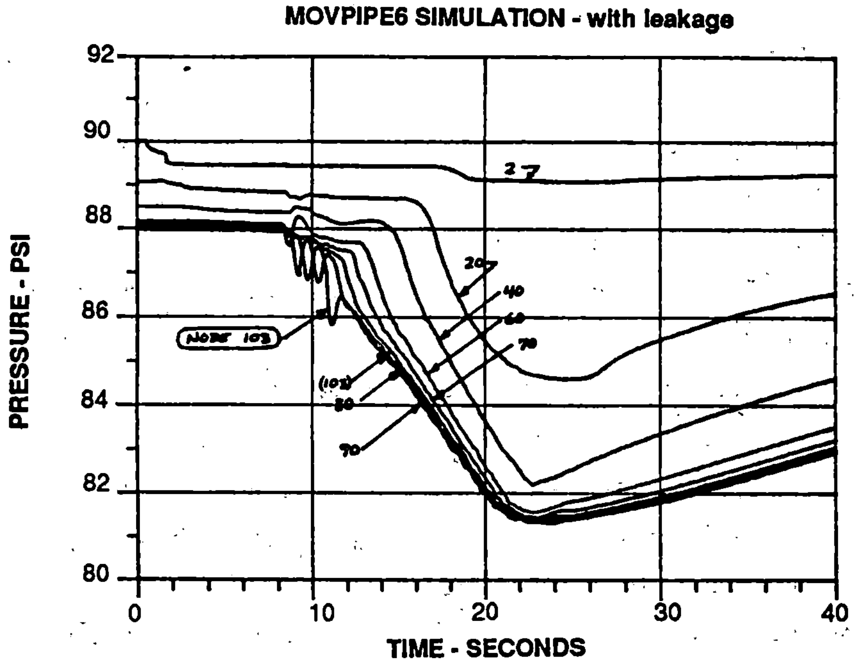


Figure 14: Pipe Pressures During UDS.

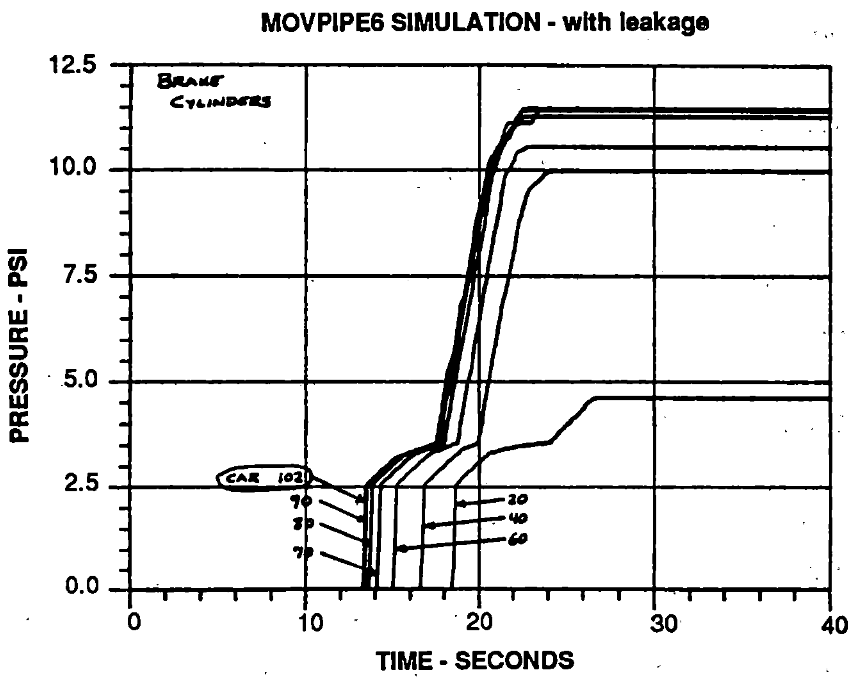


Figure 15: Brake Cylinder Pressures During UDS.

The final UDS simulation is shown in Figures 16 and 17. Run-in of cars 40-60 results in service applications which commence mid-train. This is made possible by setting the car deceleration impulses to 2g for 0.4 seconds duration. Car 60 trips first because the induced pulses build up to a critical strength there. The valve in car 102 is the second valve to apply brakes. The valves near the end of the train cause their car brakes to set prior to those near car 60, since the UDS is more pronounced at the rear end.

Figures 18, 19, and 20 show UDE's resulting from the accelerations described in trial numbers 4, 5, and 6 in the table above. In Figure 18, the whole train is decelerated without car run-in at a rate of 4.3 g for 0.3 sec. Although this represents a totally unrealistic train motion, it confirms that the valves can respond to rapid pressure variations which are (in this case) extraneous to normal braking operation.

An undesired emergency application, seen in Figure 19, is produced by having each of the last 22 cars of a 101-car train run in at a rate of -2 g for 0.12 sec. The reflected pressure pulse in the pipe causes car 101 to trip first. Once one car valve goes into emergency mode, it rapidly exhausts air from the brake pipe, thereby ensuring emergency application of all the remaining valves tied into the line.

A UDE is also caused by run-in of cars 50-70, each undergoing -4 g for 0.12 sec. Figure 20 shows simulated brake pipe pressure for this run. Note that mid-train cars go into emergency mode first during this run: the 4 g impulse is powerful enough to trip mid-train valves before the pressure pulse is able to propagate and reflect from the rear.

The next question is whether such accelerations can occur on a real train. In the run shown in Figure 19, momentary 2 g run-in decelerations (for each car in succession) might occur in rear cars if the first 79 cars of the train are able to decelerate to a velocity of 6.6 ft/sec less than that of the 80th car by the time the "slack wave" reaches car 80. The following calculations show under what conditions this might happen. Assuming that the entire train's couplings are in their extended position and that each coupling has four inches of slack, it is possible to get a run-in of train cars at this rate of deceleration. The calculation assumes that deceleration is constant for

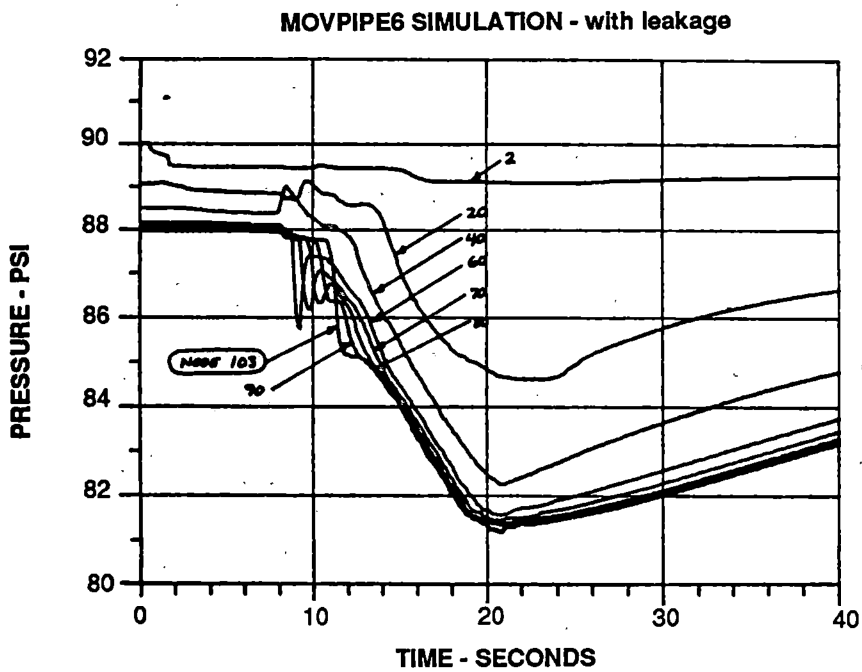


Figure 16: Pipe Pressures During UDS.

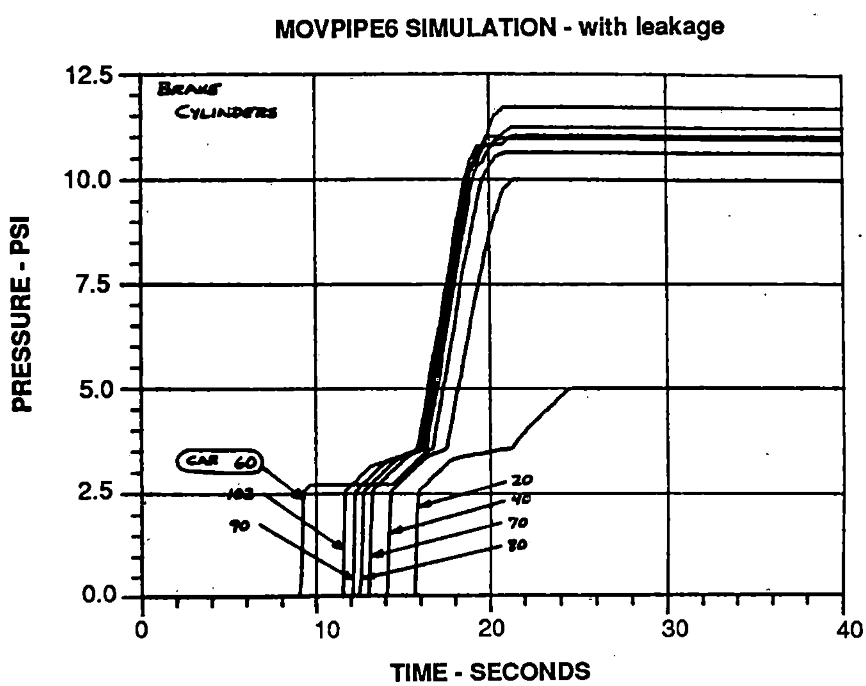


Figure 17: Brake Cylinder Pressures During UDS.

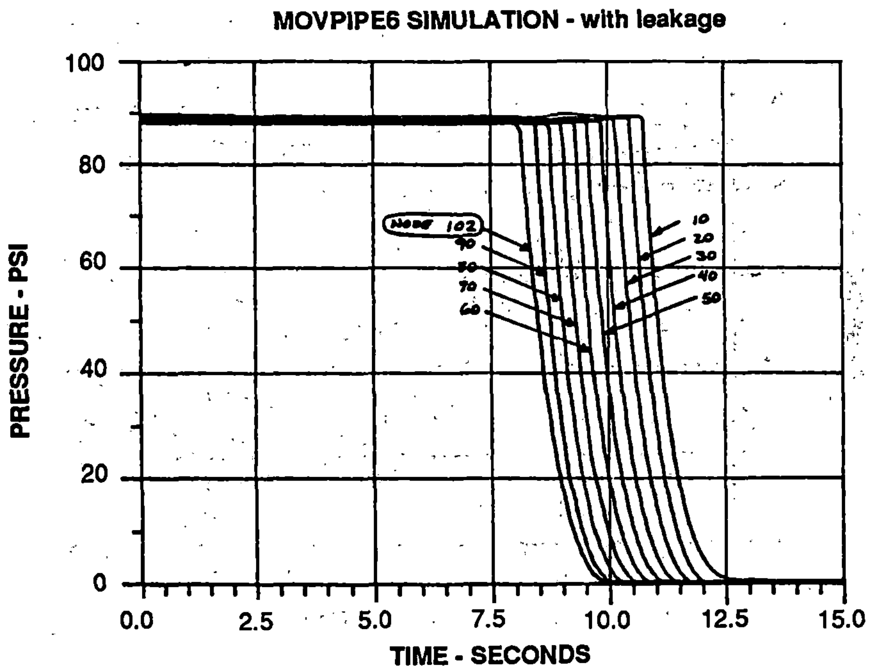


Figure 18: Pipe Pressures During Undesired Emergency Application.

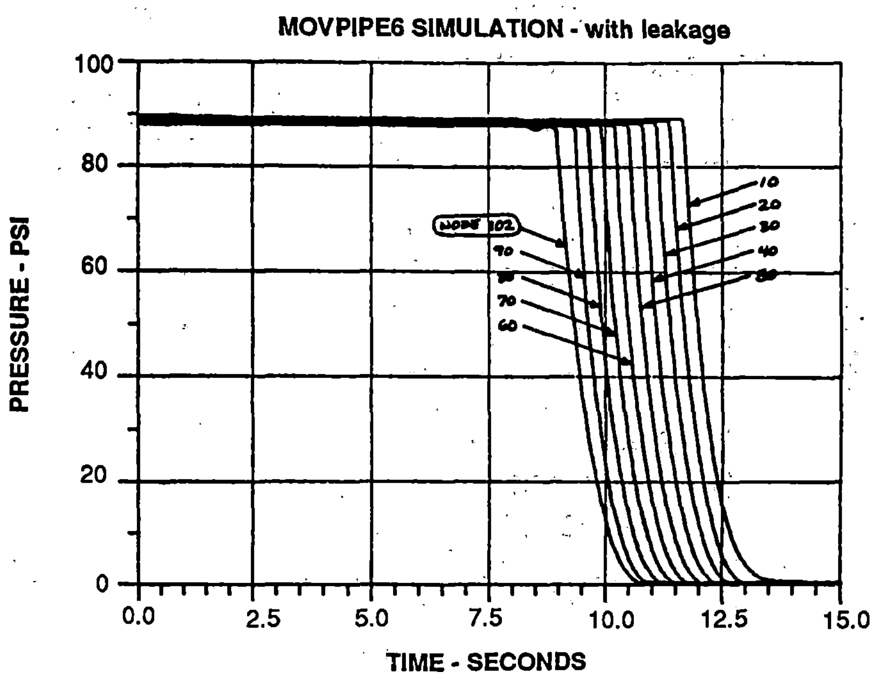


Figure 19: Pipe Pressures During UDE.

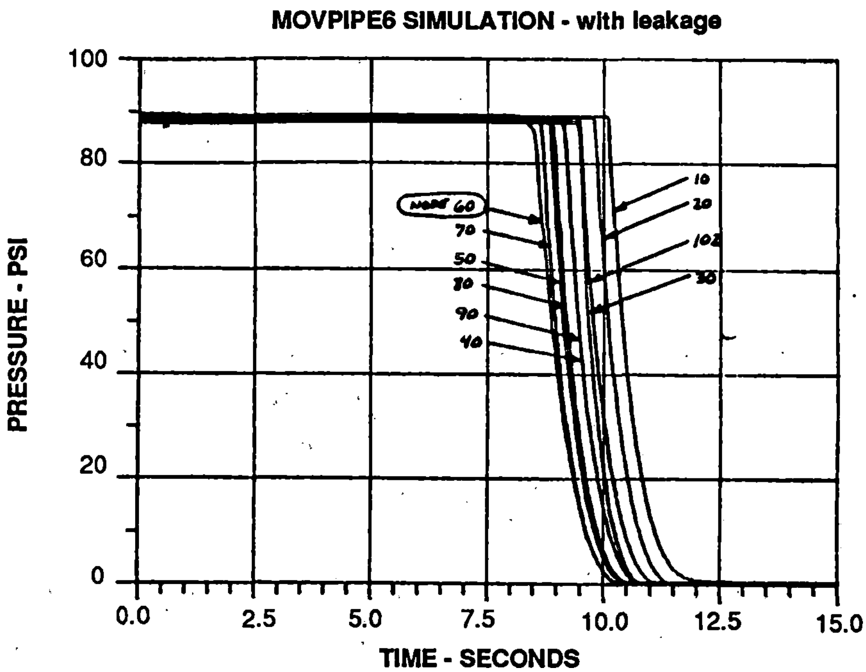


Figure 20: Pipe Pressures During UDE.

each car as it runs into the preceding car. If the velocity of car 80 is represented by V_{80}, then the slack between cars 79 and 80 varies as:

$$\Delta x_{sl} = \left(V_{80} - V_{79}\right)\Delta t + \frac{1}{2}a_{80}(\Delta t)^2,$$

where

$\Delta x_{sl} \equiv$ coupling free play (ft)

$a_{80} \equiv$ acceleration of car 80 during run-in (ft/sec^2)

$\Delta t \equiv$ duration of run-in deceleration (sec).

Rearranging to find the velocity difference between cars gives:

$$V_{80} - V_{79} = \frac{1}{\Delta t}\Delta x_{sl} - \frac{1}{2}a_{80}\Delta t$$

The velocity change required to achieve a deceleration level of 2 g for 0.12 sec is:

$$= \frac{1}{0.12 \text{ sec}}(.33 \text{ ft}) - \frac{1}{2}(-64.4 \text{ ft/sec}^2)(0.12 \text{ sec})$$

$$= 6.64 \text{ ft/sec.}$$

Next, it is necessary to show that this velocity change is possible in cars near the rear of a long train whose front end has just encountered a steep upgrade. Since the slack wave must normally travel at the speed of sound (1130 ft/sec), the first 79 cars are run-in over a period of:

(79 cars)(50 ft/car)/(1130 ft/sec) = 3.50 sec.

This is the interval in which the front end of the train must slow down to 6.64 ft/sec less than its original speed. The average deceleration of the front 79 cars would need to be:

$$a_{avg} = \frac{\Delta v}{\Delta t} = \frac{-6.64 \text{ ft/sec}}{3.50 \text{ sec}} = -1.90 \text{ ft/sec}^2.$$

A front end deceleration of this magnitude (approximately 0.06 g) could occur without dynamic braking from locomotives on a grade (angle) of 3.36^0, a 309 ft altitude gain per mile. The minimum grade could be reduced if the locomotives were braked or the rear of the train were accelerated downhill during the front end's uphill deceleration. It may be concluded that a long train could experience acceleration-induced UDE's if conditions such as these are encountered.

VII. OBSERVATIONS FROM MOVPIPE SIMULATIONS

* Critical pulse strength is approximately -12.6 psi for 0.14 sec. This is the minimum pressure change required to cause a simulated ABDW car control valve to go into emergency mode.

* It may be possible for some real valves to be more sensitive than the ABDW valves modeled by MOVPIPE since variations in parameters

such as piston friction, orifice area (e.g., dirt may cause constrictions in passages), and return spring rates can affect valve performance.

* Pulse-steepening occurs when a pressure wave is reflected from the tail end of the brake pipe. This could cause the brakes to be set at the rear of the train as a UDS or UDE.

* Run-in of cars results in small pressure pulses created by individual cars. If conditions are right (i.e., if the rate of run-in—the speed of the slack wave—coincides with the speed of sound in the brake pipe), these small pulses superimpose, thereby building up in strength. This is the situation most likely to precipitate undesired braking operations.

* Reducing the brake pipe pressure effectively reduces the air mass within, which weakens the acceleration-induced pulses.

* Pulse superimposition is stronger in trains with 50-ft cars than in those with 100-ft cars (according to the friction model being used) because the added air mass of the longer cars does not overcome the increased car-to-car frictional losses. In other words, the stronger pulse generated by a long car loses some of its additional strength by the time it reaches the adjacent car, due to the longer distance it must travel.

* It is reasonable to expect that at lower values of run-in deceleration, the last car on the train will be most likely to go into a UDE or UDS because of pulse-steepening. For much higher decelerations starting at the head end, the middle cars will tend to trip first.

* The speed of propagation of pressure waves in the brake pipe depends both on the local celerity (speed of sound) and the speed of air flow within the pipe.

VIII. SUMMARY REMARKS:

What has been discovered up to this point is that car motion influences the air flow within the brake pipe, and that the phenomenon is particularly acute at the tail end of a train. Furthermore, coupling slack can lead to instances of extreme car acceleration, producing small pressure pulses in the brake pipe. In certain cases, slack run-in patterns can give rise to superimposition of induced pressure pulses which may perturb the air in the brake pipe enough to trigger brake valves into action. Although the set of circumstances under which this can happen is limited, the findings this paper presents give some validation to the hypothesis that train motion may be an important facet of the undesired braking problem.

Suggestions for future investigations include tying in a more complete train motion simulator (such as TOS or TOES), studying the effect of varying the characteristics (parameters) of car valves, and implementing the micro-model of the brake pipe and its branch lines. It is expected that these investigations will lead to a correlation between the values of car valve parameters and their effect on sensitivity of the valves to transient pressure pulses. Further, these studies may show that the dynamic interactions between the valves and their branch lines may be marginally stable, further sensitizing the braking system to the motion-induced brake pipe pulses.

IX. REFERENCES

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