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THERMAL MEASUREMENTS OF COMMUTER RAIL WHEELS UNDER REVENUE SERVICE CONDITIONS

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This report documents the test objective, procedure, and equipment used during the execution of the New Jersey Transit Operational Field Test conducted under the FRA Cracked Wheel Investigation. The report also includes a presentation of all data gathered during the test procedure and illustrates the general trends and characteristics of the data as witnessed during acquisition. Included in appendices are technical insights into the development of the unique equipment used in this test and complete thermal measurement data sets. The objective of this field test was to acquire empirical thermal data on commuter railroad wheels during stop braking procedures. The test was conducted using New Jersey Transit Rail Operation's revenue track, primarily on the Northeast Corridor, as well as Arrow III rail cars, train crews, and engineering support.

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SUMMARY

This report documents the test objective, procedure, and equipment used during the execution of the New Jersey Transit Operational Field Test conducted under the Federal Railroad Administration's (FRA) Cracked Wheel Investigation. The report also includes a presentation of all data gathered during the test procedure and illustrates the general trends and characteristics of the data as witnessed during acquisition. Included in appendices are technical insights into the development of the unique equipment used in this test and complete thermal measurement data sets. Further data analysis is being conducted at the Volpe National Transportation Systems Center (VNTSC); results of this analysis will be included in subsequent reports.

The objective of this field test was to acquire empirical thermal data on commuter railroad wheels during stop braking procedures. Data obtained will be used to validate calculations of temperature distributions made using an analytical thermal stress analysis model, thus, gauging the accuracy of the model's input assumptions and overall performance. The test was conducted using New Jersey Transit Rail Operation's (NJTRO) revenue track, primarily on the Northeast Corridor, as well as Arrow III rail cars, train crews, and engineering support. Support for the testing operation was provided by the FRA, the VNTSC, and NJTRO. ENSCO, Inc., Springfield, Virginia, provided wheel instrumentation, data acquisition equipment, and logistics support for the field test. The test took place on October 20 & 21, 1992.

Two new, S-plate, wrought, railroad wheels were instrumented as test wheels to record temperatures while under in-service conditions. The test procedure employed a variety of instrumentation types including thermocouples, infrared thermal imaging, pyrometers, and various pressure transducers. Serving as the primary measurement device, thermocouples were installed on and within the railroad wheels at specific locations to gather temperature data on the plate surface and within the wheel rims. Thermal imaging, provided by Baird Infrared, Inc., Wilmington, Delaware, was used to gather surface temperature values from the two test wheels as well as from other wheels on the same consist and from revenue trains as they passed the measurement locations. Handheld pyrometer temperature measurements were used to calibrate the thermal imaging equipment and to measure surface temperatures at locations on the wheels that were not visible to the imaging lense. Finally, train car parameters including brake cylinder and #16 brake pipe pressures were monitored using pressure transducers. Train speed was also recorded from the speed card within the car's instrumentation system.

The test procedure was very successful in simulating in-service braking events as well as in conducting severe braking exercises. Temperature data were gathered from all measurement devices while performing a total of 28 data runs covering two full nights of testing. The instrumentation system was sufficiently durable to enable a variety of test scenarios to be executed, including 100 m.p.h.-to-0 m.p.h. full-service stops, simulated station-to-station stop sequences, and emergency stop scenarios. General trends in thermocouple temperature data include:

1. Temperature gradients, within the wheel rims, were seen in all braking events and thermocouple temperature measurements closest to the tread surface were always higher than those deeper in the rim during braking.

2. During free-running periods after a braking cycle, temperatures deeper in the wheel rim were consistently higher than those closer to the tread surface.

3. Peak rim temperatures were recorded between 20 and 50 seconds after initial brake application.

4. Heating and cooling rates were always higher closer to the tread surface than deeper in the rim.

5. Fifty to 90 seconds were required for thermocouple temperature measurements to drop to one-half of their peak after a braking event.

6. Average gradients between temperatures measured at 0.1" and 0.5" nominal depths were:

WHEEL POSITION #	DEGREES (F)
4	160.67
6	215.17
7	143.83

7. Little time delay was seen between initial brake application and rim temperature rise.

1. INTRODUCTION

1.1 BACKGROUND

This report is the second in a series on the results of an engineering study of the effects of service loads on railroad vehicle wheels. The study was initiated in September 1991 in response to a request for assessment of contributing factors and corrective actions taken regarding high rates of crack occurrence in certain multiple unit (MU) powered cars used in commuter service. The ultimate goal of the study is the evaluation of safe limits on performance demand (weight carried per wheel, maximum speed, vehicle braking rate) as a function of wheel design, material selection, and manufacture as well as percentage of braking effort absorbed through the wheel tread in service. The models developed in the study are intended to provide the capability for similar engineering design analyses of other railroad vehicle wheels besides the types used on MU cars.

Previous engineering tests include a review of wheel maintenance records of the affected railroads to confirm the general nature of the crack occurrence patterns, destructive testing of two service-worn, thermally cracked wheels to obtain quantitative data on the number and size of the cracks, and destructive saw-cutting of new and service-worn wheels for purposes of estimating the residual stresses in their rims. Reports covering the saw-cutting and the wheel crack census tests are being published separately. Metallurgical examinations of wheel samples, including metallographic and fractographic studies as well as hardness tests, were also conducted. The results from these tests were used as empirical references in the formulation of finite element computer modeling programs designed to analyze the thermal and mechanical stress state of railroad wheels and to evaluate the potential for different types of wheels to resist cracking under various combinations of service conditions. Chart 1 illustrates the organization of models and tests required to develop a procedure to estimate wheel stresses. The shaded block denotes the test covered in this report.

1.2 FIELD TEST OBJECTIVES AND SCOPE OF REPORT

The purpose of the New Jersey Transit Operational Field Test, the subject of this report, was to determine actual in-service commuter rail wheel temperatures and to quantify any thermal gradients generated within the wheel rim during stop-braking. This information was needed to validate the elastic material behavior assumption made in the construction of the thermal stress analysis model mentioned above. A direct comparison between wheel temperature distributions calculated from the thermal model and empirically determined temperature data measured near the wheel tread under stop braking conditions was needed. To make an adequate comparison, it was necessary to quantify the thermal energy transferred to the wheels under stop-braking, and the thermal gradient within the rim resulting from this energy transfer, under in-service conditions. To this end, a field test was scheduled with New Jersey Transit Rail Operations (NJTRO) to gather wheel temperature data using specially designed instrumentation developed under the FRA Cracked Wheel Investigation program. The test was conducted on October 20 & 21, 1992.

The wheel temperature data obtained during this test was used by the Volpe National Transportation Systems Center (VNTSC) to make the comparison outlined above. The scope of this report is limited to a description of the test objectives, equipment, and test procedure; a presentation of the acquired data; and, a discussion of general trends in the data that were observed during data acquisition.

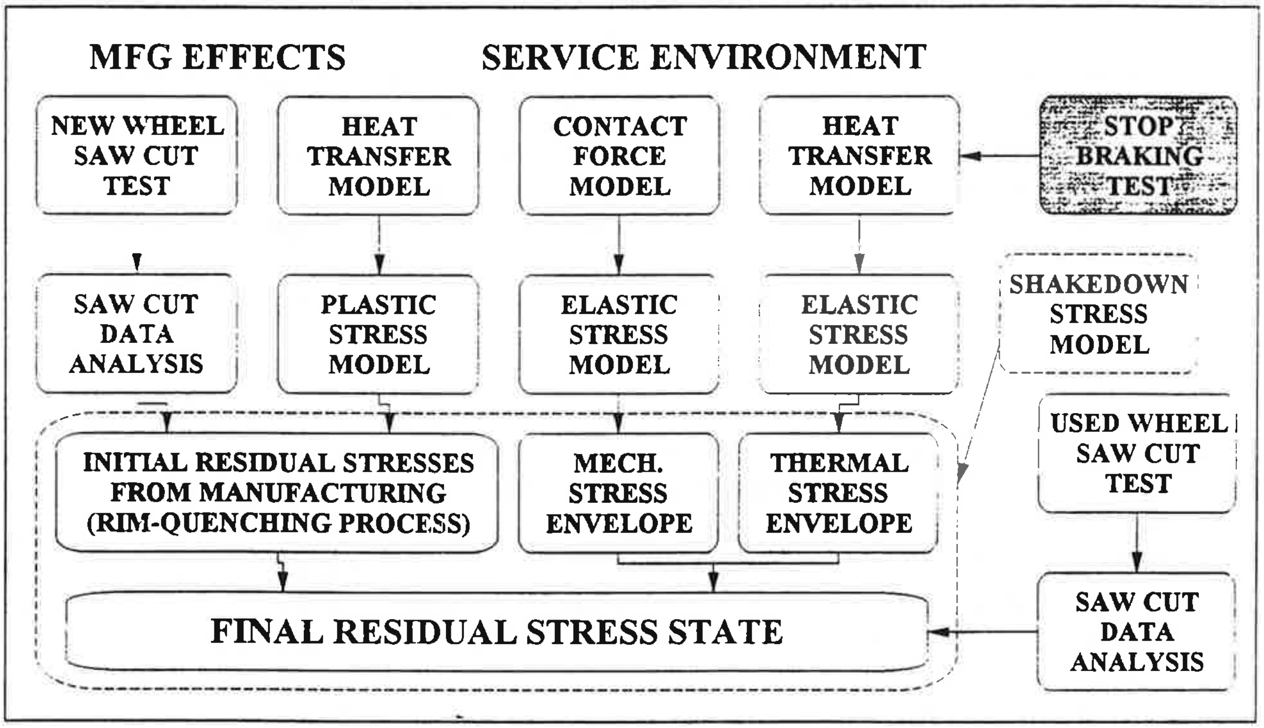


Chart 1 Analysis Diagram

2. TEST EQUIPMENT AND SET-UP

2.1 WHEEL INSTRUMENTATION

2.1.1 Requirements and Test Wheels

The objective of this test, measurement of the wheel's thermal state under in-service conditions, required the development of a unique measurement technique. Temperatures were to be measured on the surface of the wheel plate and at precisely defined radial locations within the wheel rim, near the tread surface, in order to accurately describe thermal gradients generated by stop-braking procedures. Figure 1 illustrates the measurement location requirements. Two locations, 180 deg. apart, on each wheel were instrumented as shown. A total of three new, wrought, S-plate wheels (provided by NJT) were fully instrumented, two for the actual test procedure and one to serve as a spare.

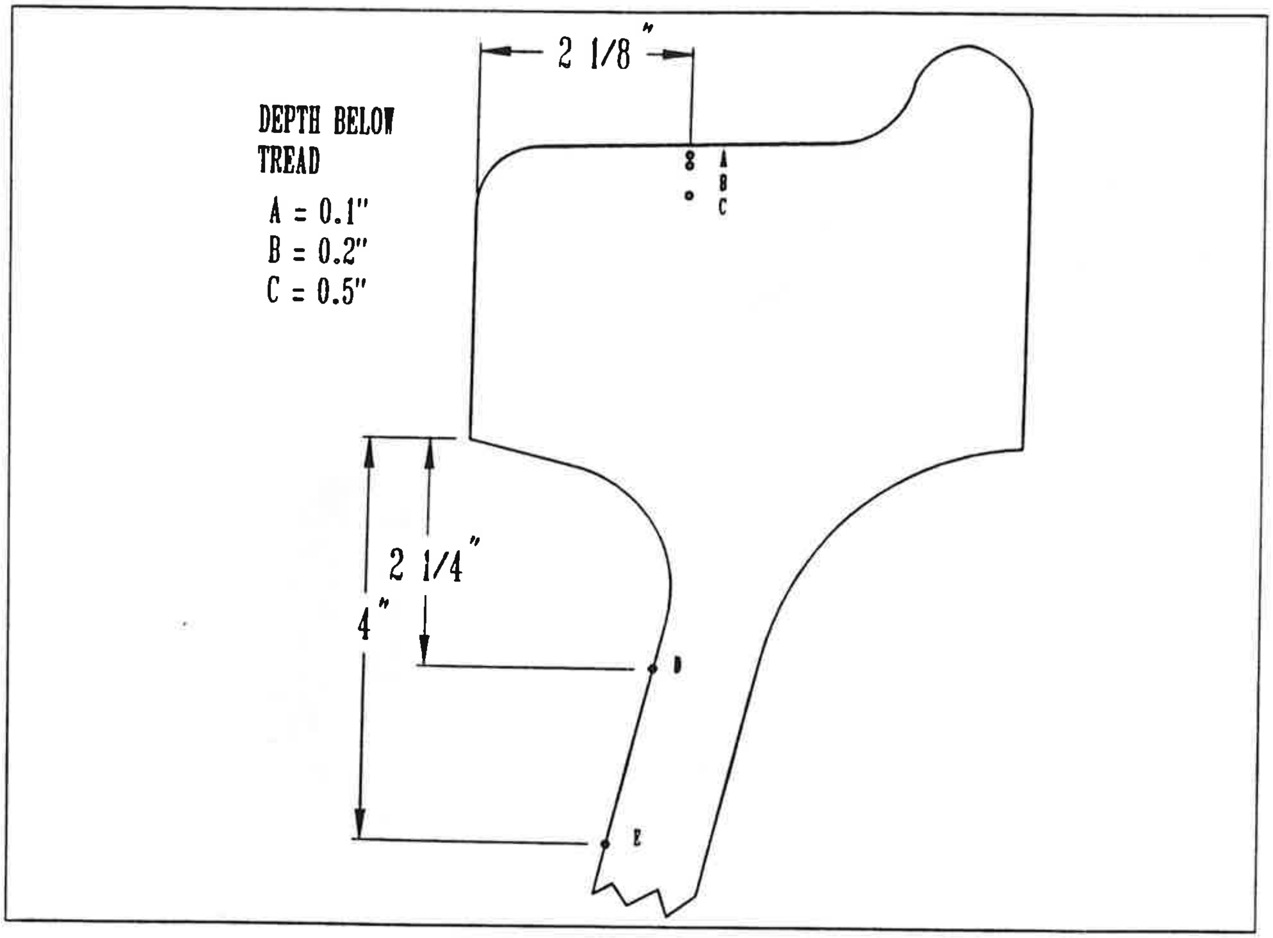


Figure 1 **Temperature Measurement Locations**

2.1.2 Instrumentation

Analytical models predict that the thermal energy transfer between the brake shoes and the wheel tread, during braking, occurs at a very high rate and generates very steep thermal gradients within the wheel rim. Therefore, the instrumentation used in this test required a rapid response rate (approx. 30 deg./sec.) in order to accurately record the temperature changes within the wheel rim. Type-K thermocouples with 0.003" diameter conductors were chosen for temperature measurements inside the wheel rim. After consideration of the mechanical and electrical environment in which the measurements were to be made, the thermocouples chosen were ungrounded (aluminum-oxide insulation) and had a stainless steel sheath. This choice proved to be a good compromise between mechanical and electrical integrity and obtaining an adequate thermal response rate. Results from preliminary response tests confirmed that these thermocouples would meet the field test's response requirements. The thermocouples used on the plate locations were also Type-K, but were equipped with a self-adhesive backing for use on surface applications.

2.1.3 Thermo-Plug

Thermal measurements were to be made under in-service conditions, therefore. in the interest of maintaining as much of the mechanical and thermal integrity of the wheel as possible, it was decided that temperature measurements at positions A, B, and C (Figure 1) would be made using a single measurement device, as opposed to three separate devices, to minimize the influence of the measurement equipment on the wheel's normal thermal behavior. This device, referred to as the thermo-plug, is illustrated in Figure 2.

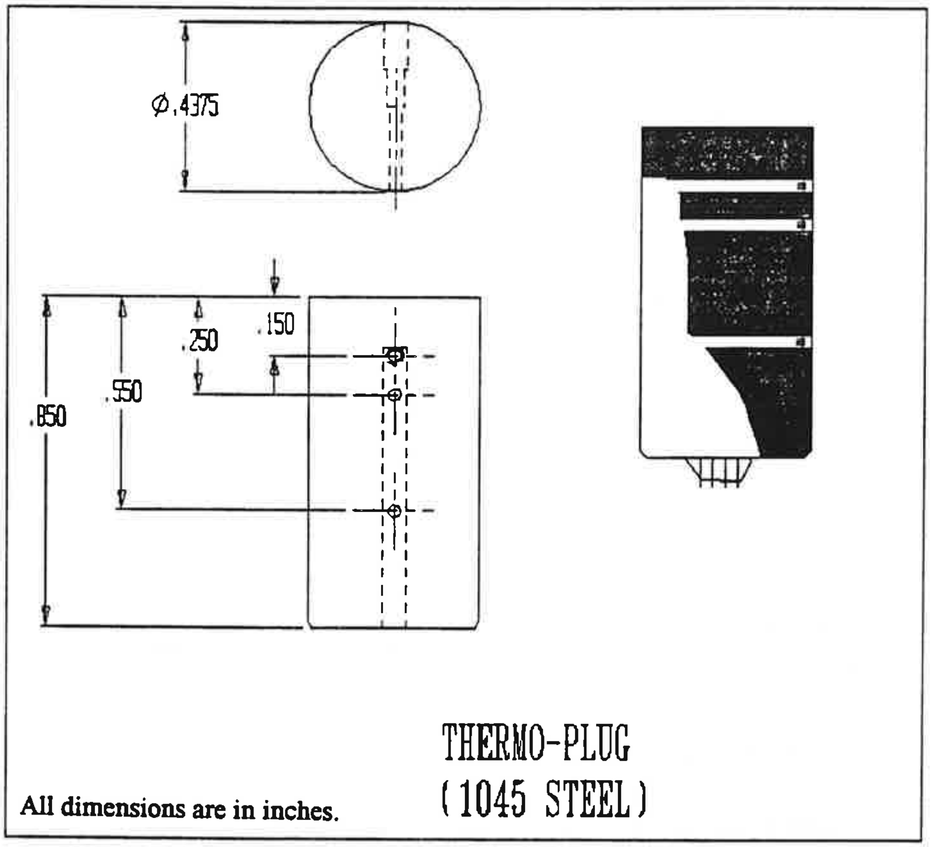


Figure 2 **Thermo-Plug Assembly**

The thermo-plug was machined from 1045 steel; chosen because it closely resembles the mechanical and thermal characteristics of wheel steel. As shown in the figure, the three thermocouples are positioned in the thermo-plug in horizontally drilled holes at the desired spacing per the requirements of the experiment. Excess material was left on the top of the thermo-plug to allow the plug to be hand-contoured to the wheel tread profile after installation. Silver solder was used to hold the thermocouples in position and to fill the construction relief in the plug. The assembly was designed to be press-fit into a machined hole in the test wheel using a hydraulic press. The force required to fully seat the thermo-plug in the wheel was approximately 800 lb. Given that the thermo-plug was constructed from materials with similar thermal characteristics, and that no voids are present in its design, it was felt that the placement of the plug within the wheel rim would not significantly alter the thermal characteristics of the wheel and therefore, would provide an accurate measurement of temperatures within the rim. Appendix I of this report describes the construction, testing, and implementation of the thermo-plug assembly.

2.1.4 Wheel Modifications

Modifications to the test wheels were necessary to accommodate the thermo-plug assembly. Figure 3 illustrates these modifications. Detailed drawings of the test wheel modifications are included in Appendix I.

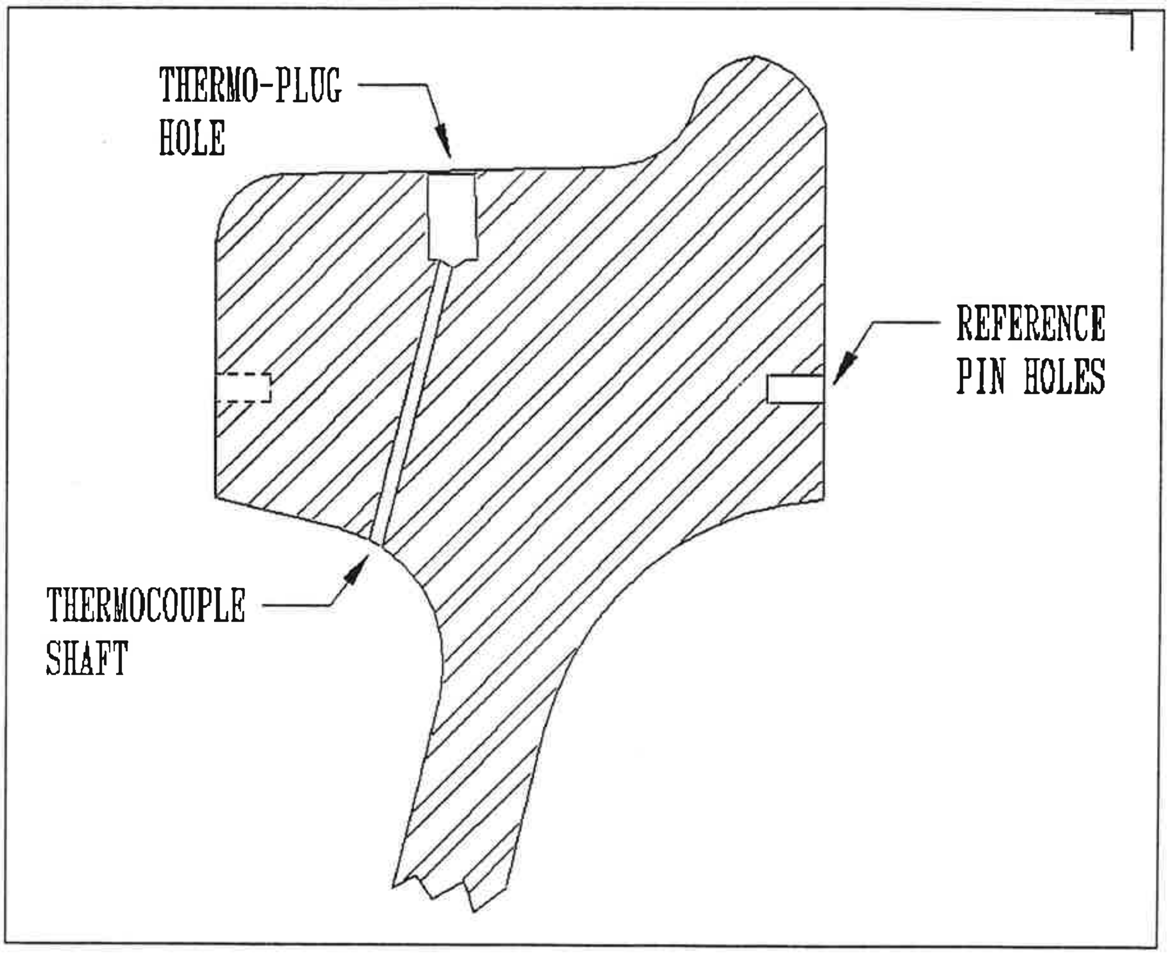


Figure 3 Wheel Modifications

The thermo-plug hole was machined to provide an interference fit with the thermo-plug, to retain the assembly in place while conducting data runs. The hole was oriented perpendicular to the tread surface of the wheel and located near where the center of the brake shoe contacts the

wheel. The thermocouple shaft allowed the three thermocouples to pass through the rim of the wheel to connect to the data acquisition system hardware. The relief in the bottom of the thermo-plug hole provided clearance to bend the thermocouples so that they would thread through the offset-angle thermocouple shaft. Finally, three reference holes were drilled into the rim faces (2 on the field face, 1 on the gage face) to hold hardened-steel pins used in the thermo-plug position measurement procedure. This procedure and its unique equipment are discussed in the Test Results section of this report as well as in Appendix I.

External wheel and axle assembly modifications, shown in Figure 4, include grinding and cleaning the plate surface to facilitate secure mounting of the instrumentation wiring on the wheel, and drilling and tapping the end of the axle for the slip-ring housing mounting bolts. After wheel instrumentation, NJT's Meadows Maintenance Complex personnel assembled two of the test wheels into two complete wheelsets and slip-rings were installed on the axle ends. All wiring for the instrumented wheels (8 thermocouple wire pairs on each wheel) passed through the slip-rings enroute to the data acquisition system.

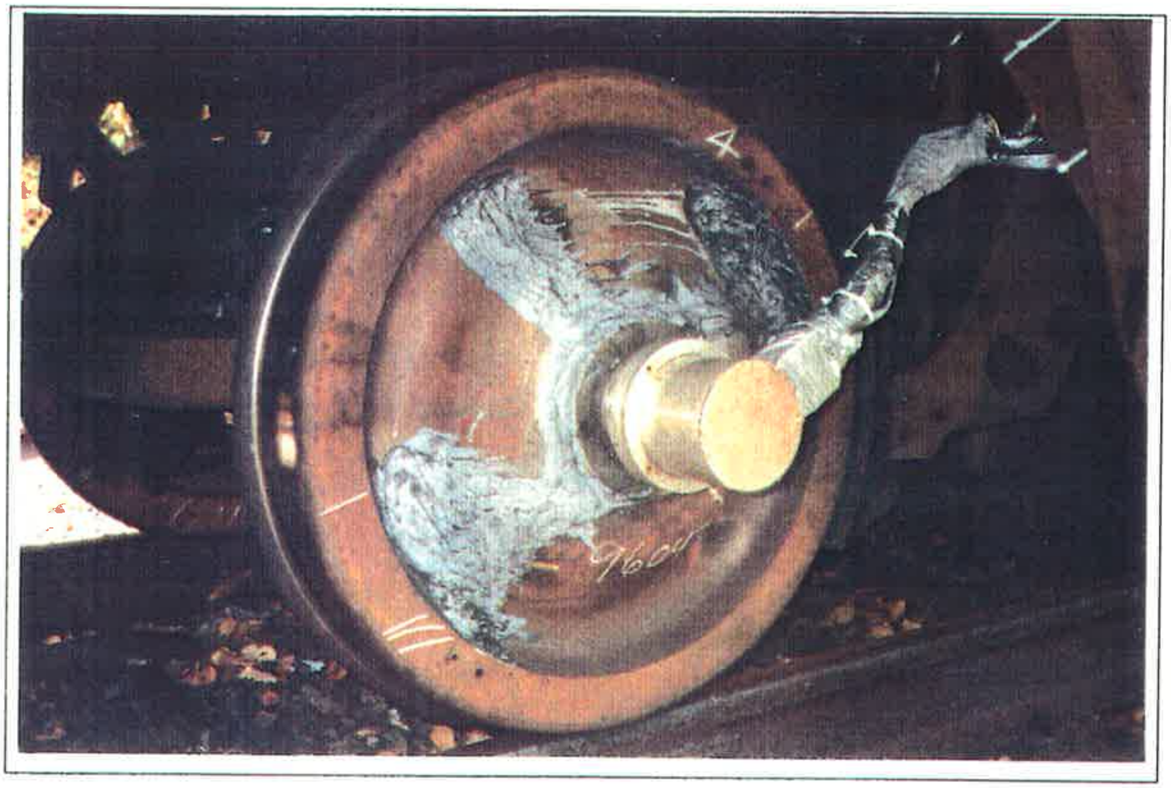


Figure 4 Wheel and Axle Assembly

2.2 DATA CHANNELS

Figure 5 lists all the data acquisition channels monitored during the test and the location of each signal on the test car. The first 17 channels were thermocouple temperature measurement locations while the remainder, except for speed and event marker, were pressure signals from

NJT-supplied transducers mounted on the vehicle. The speed signal was obtained from the speed card located in the car's instrumentation system and the event marker was a keyboard-entered digital switch used during the speed calibration procedure.

COMPUTER #	CHANNEL #	WHEEL #	POSITION #	DEPTH
0	1	L 1	3	0.096"
1	2			0.196"
2	3			0.496"
3	4		4	0.101"
4	5			0.201"
5	6			0.501"
6	7		PLATE	2.25"
7	8		PLATE	4.0"
8	9	L 2	6	0.093"
9	10			0.193"
10	11			0.493"
11	12		7	0.098"
12	13			0.198"
13	14			0.498"
14	15		PLATE	2.25"
15	16		PLATE	4.0"
16	17		AMBIENT	UNDER CAR
17	18	SPEED		
18	19	BRAKE CYLINDER PRESSURE B		
19	20	BRAKE PIPE PRESSURE		
20	21	BRAKE EQUILIZATION PRESSURE		
21	22	BRAKE #16 PIPE		
22	23	BRAKE CYLINDER PRESSURE A		
23	24	SPARE		
24	25	SPARE		
25	26	SPARE		
26	27	SPARE		
27	28	EVENT MARKER (0-1)		
28	29	SPARE		
29	30	SPARE		
30	31	SPARE		
31	32	SPARE		

Figure 5 **Data Channels**

2.3 DATA ACQUISITION SYSTEM

The data acquisition system used in this experiment was based around an IBM-compatible 486/33MHZ PC running specially designed software which read, displayed, and stored all the data. The computer received the data signals via two, 16-channel, Metrabyte analog-to-digital (A/D) cards which were connected to a custom-made signal conditioning unit. This unit housed all the analog signal conditioning modules and filtering (4 Hz, low pass) equipment necessary to process all the raw data signals, both for the thermocouple channels as well as for the speed and air pressure channels. All signal conditioning equipment was manufactured by Analog Devices. The data sampling frequency of the acquisition system was 4 Hz. The instrumentation system flow-chart is displayed in Figure 6.

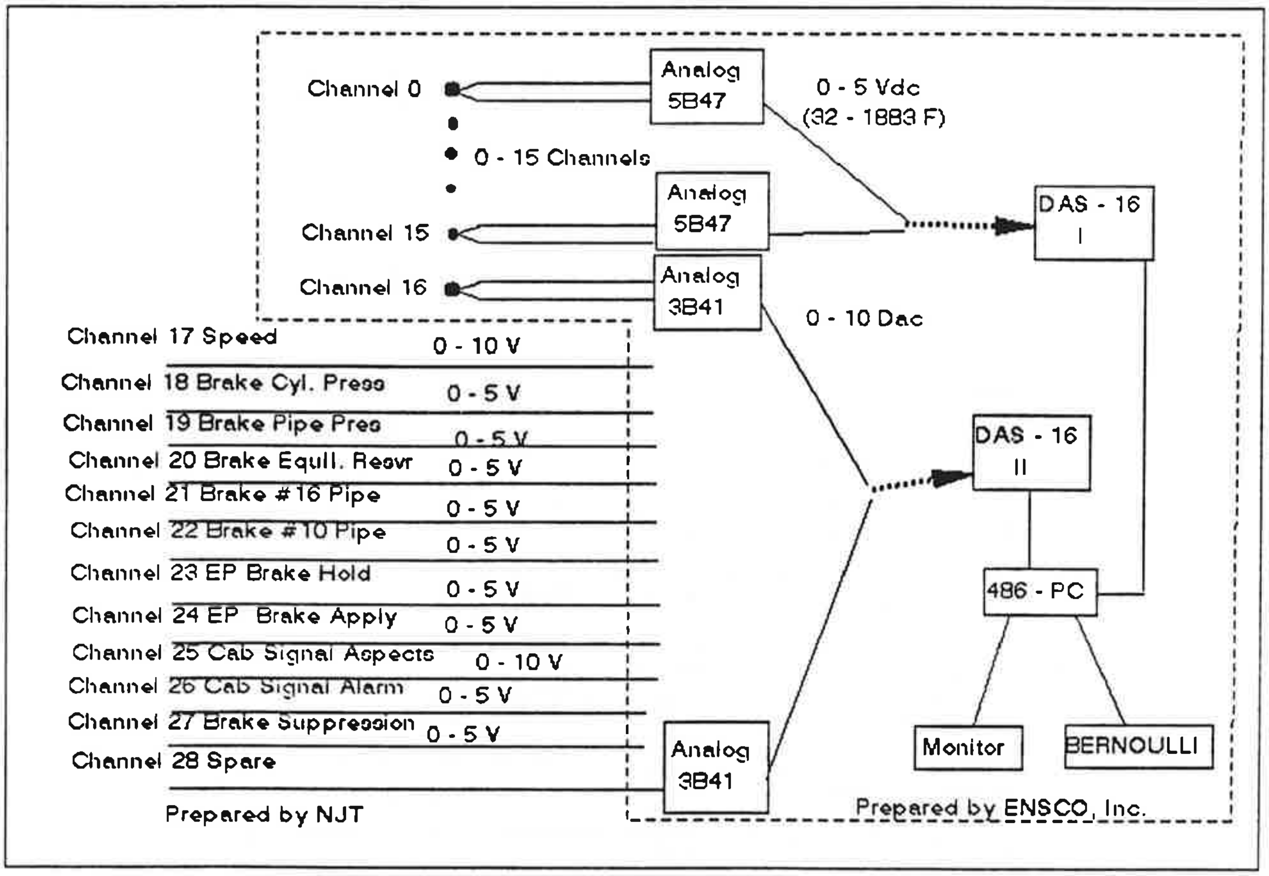


Figure 6 Instrumentation Diagram

2.4 DATA PRESENTATION

The final presentation for each run is a series of graphs illustrating the temperature measurements obtained from the thermo-plugs along with the corresponding brake cylinder pressure and speed data, plotted against time. Appendix II contains sample graphs from all of the data runs and displays the temperature data obtained from three of the four thermo-plugs (the fourth thermo-plug was damaged during the instrumentation installation procedure).

2.5 INFRARED THERMAL IMAGING

2.5.1 Objectives

In addition to the thermocouple instrumentation, infrared thermal imaging was also employed to measure surface temperatures of both test wheels on selected test runs. Additional data were also gathered from thermographic inspection of revenue train wheels. The specific objectives in applying thermographic technology during this investigation were:

1) To quantify the relationship between internal and surface wheel temperatures;

2) To evaluate the suitability of thermal imaging techniques for assessing temperature variations between different wheels on the same car, between different vehicles within the consist, and between different trains operating over the same territory; and,

3) To use as a back-up measurement system in case of wheel instrumentation failure.

2.5.2 Data Products

Baird Infrared Technology, Inc., located in Wilmington, Delaware, was contracted to provide infrared imaging services in support of this experiment. Data collection was accomplished using an Inframetrics Model 600 thermal imaging system and an Inframetrics ThermaGRAM computerized image processing system analyzed the acquired data. VHS videotape was used for data recording and storage.

Test data recorded on VHS videotape is organized in the same order as when trains arrived or passed the test site. Train and/or car numbers were recorded where possible. When recorded at the Princeton Junction station, trains traveling left-to-right were considered west-bound. At the Metropark station, trains traveling right-to-left were considered west-bound. A complete list of all trains recorded as well as detailed results from selected images are contained in Appendix III. Copies of the thermal imaging videotape are available upon request from ENSCO, Inc.

2.6 PYROMETER MEASUREMENTS

A hand-held pyrometer was used to measure surface temperatures on the test wheels at selected instances while the test train was stopped. The pyrometer consists of a thermocouple in a special housing which allows surface temperature measurements to be made by hand. Included on the device is a digital display temperature indicator. This instrument provides highly accurate temperature measurements within the Type-K thermocouple range and was used to gage the accuracy of the thermal imaging measurements. Data comparison between the two techniques revealed a general order of magnitude similarity and served to support the validity of the thermal imaging measurements as well as to provide surface temperature measurements at locations on the wheel that were not visible to the thermal imaging system. The pyrometer also provided corroborating evidence supporting in-wheel temperature measurements. Measured surface temperatures, while different than those made in the rim bulk, were close enough to in-rim temperatures to provide independent verification of in-rim measurement accuracy.

2.7 TEST SCHEDULE AND PARTICIPANTS

2.7.1 Test Schedule

Instrumentation of the test consist was performed at New Jersey Transit's Meadow's Maintenance Complex (MMC) in Newark, New Jersey. Throughout the test procedure, the test consist was stored at Matawan, New Jersey on the NJT North Jersey Coast Line and traveled from there to the Northeast Corridor for data acquisition runs.

The field test schedule was as follows:

Oct. 15, 1992 To Oct. 18, 1992	ENSCO crew arrived at NJT-MMC Assembled test consist and instrumented wheelsets Assembled instrumentation on test car Final wheel preparations Instrumentation calibration and checkout
Oct. 19, 1992	Run-light from MMC to Matawan, New Jersey First "live" test of measurement system Test wheel break-in period
Oct. 20-21, 1992	The first "official" field test Testing began at 23:18 hr. on Oct. 20 Speed signal calibration (measured mile) N.E. Corridor: Test between County and Fair Various test scenarios Return to Matawan at 05:30 hr. on Oct. 21
Oct. 22, 1992	The second field test Began at 00:03 am on Oct. 22 Test N.E. Corridor between County and Fair Thermal imaging taken at Princeton Junction and Metropark Various test scenarios Return to Matawan at 04:30 hr. on Oct. 22
Oct. 22, 1992	Consist returned to MMC Instrumentation disassembled

2.7.2 Participants

Fourteen people participated during the first day of testing on Oct. 20, 1992.

1.	Kevin Kesler	Rail Program Manager	ENSCO, Inc.
2.	Don Gray	Research Manager	FRA, OR&D
3.	Jeff Gordon	Mechanical Engineer	VNTSC
4.	Shawn Yu	Mechanical Engineer	ENSCO, Inc.
5.	Tom Dohn	Electrical Engineer	ENSCO, Inc.
6.	Tom Lutz	Inspector	FRA, Safety
7.	Yim Har Tang	Mechanical Engineer	VNTSC
8.	Oscar Orringer	Mechanical Engineer	VNTSC
9.	Ben Smith	Dir. of Tech. Support	NJT
10.	Jerry Deily	Electrical Engineer	FRA
11.	Sylvester Remorg	Mechanical Engineer	NJT
12.	John Vogler	Signal Maintenance Engr.	NJT
13.	Bob McCown	Program Manager	FRA, OR&D
14.	Cam Stuart	Project Manager	ENSCO, Inc.

Eleven people participated on Oct. 21, 1992.

1.	Kevin Kesler	Rail Program Manager	ENSCO, Inc.
2.	Don Gray	Research Manager	FRA, OR&D
3.	Shawn Yu	Mechanical Engineer	ENSCO, Inc.
4.	Tom Dohn	Electrical Engineer	ENSCO, Inc.
5.	Oscar Orringer	Mechanical Engineer	VNTSC
6.	Ben Smith	Dir. of Tech. Support	NJT
7.	Sylvester Remorg	Mechanical Engineer	NJT
8.	John Vogler	Signal Maintenance Engr.	NJT
9.	Bob McCown	Program Manager	FRA, OR&D
10.	Cam Stuart	Project Manager	ENSCO, Inc.
11.	Carlton Dawson	Test Engineer	Baird, Inc.

3. TEST PROCEDURE

3.1 CONSIST DESCRIPTION

The test consist was comprised of a married pair of NJT Arrow III cars (No. 1391 and No. 1390) with car 1391 housing all instrumentation and data acquisition equipment. Testing on the Northeast Corridor required that two non-instrumented cars (No. 1412 and No. 1413) be added to the test consist to provide sufficient tractive power for testing at 100+ mph. Statistics on the consist were obtained from each car's placard and are listed below. Figure 7 shows the test consist located at Matawan, New Jersey on the NJ Coast line.

Car #1391:	Instrumentation car	
	Instrumented wheels L1 and L2 (B-end, handbrake position)	
	New "S" plate wheels (L1 and L2)	
	Good, worn, brake shoes on test wheels	
	Weight:	Total = 120,400 lbs
		A - end = 59,700 lbs
		B - end = 60,700 lbs
Car #1390:	Weight:	Total = 122,800 lbs
		A - end = 59,200 lbs
		B - end = 63,600 lbs
Car #1412:	Weight:	Total = 122,500 lbs
		A - end = 59,100 lbs
		B - end = 63,400 lbs
Car #1413:	Weight:	Total = 120,400 lbs
		A - end = 60,200 lbs
		B - end = 60,200 lbs

Figure 7 Consist at Matawan

3.2 TEST ZONES AND CONDITIONS

The test train was operated by a regular New Jersey Transit (NJT) train crew. Test operations were conducted primarily on Northeast Corridor (NEC) track #3 between County and

Fair interlocking. However, some data were collected while the train was transported to and from the NEC on the Jersey Coast Line and from MMC to Matawan, New Jersey. Test conditions on both nights were similar, with ambient temperatures ranging from the mid-30's to 50 degrees F and a dry wheel/rail interface, free of rust or grease.

An initial car inspection was performed to assess the condition of all wheels and brake shoes on the consist. This inspection revealed a few wheels with visible thermal cracks and some with blued edges, but overall, the consist was in good condition. Detailed notes of this inspection are included in Appendix II.

The instrumented wheels were new, "S" plate, wrought wheels having only a few "break-in" miles of wear. The brake shoes at the test wheel positions were in good, worn condition, approximately 1" thick. The brake shoe at test wheel #L1 had three cross-cracks, two of them about 1/8" wide. One was very small, located in the middle of the shoe. The two larger cracks were located at about 4" from each end of the shoe. The brake shoe at test wheel #L2 had three cross-cracks, one about 1/8" wide located 4" from the top end of the shoe. The other two were very small, located at about 2.5" from the bottom side of the shoe. The condition of the test wheel brake shoes was consistent with the condition of other shoes on the consist.

3.3 DATA ACQUISITION AND INSTRUMENTATION CALIBRATION

3.3.1 Run Scenarios

Numerous data collection test runs were performed during the field test including "official" test runs as well as some system shakedown tests. All recorded data for these runs as well as a testing run summary are included in Appendix II. In general, test runs were made at the highest speeds attainable using varying levels of brake reduction (full, 10 lb., and 20 lb. reductions were typical) to slow the train. Also, speed ratcheting runs were completed where the train speed was cycled from maximum to some slower speed, using various brake reduction rates, and the cycle was repeated numerous times within a single test run. The overall goal of the run scenarios was to simulate in-service wheel thermal loading conditions.

3.3.2 Data Collection and Display

The data acquisition software used in this test was designed to both display and store the data as it was collected. Therefore, near real-time data analysis was possible by viewing the computer monitor, limited only by a screen refresh frequency of once per second. In addition to the computer monitor data display, a second computer was used to generate graphs showing temperature plotted against time for each data run after the run's completion. The raw binary data file was converted to ASCII, transferred to the post-processing computer via floppy disk, then imported into a spreadsheet program for graphing. For each data file, the temperature data from a single thermo-plug (3 thermocouples) were plotted with the brake cylinder pressure and speed data versus time. This enabled the participants to review the results of a particular run and to determine the subsequent run scenarios based on their findings. All data files were time stamped

and stored on Bernoulli 44 megabyte diskettes. Figure 8 shows the data acquisition system on car #1391.

Figure 8 Data Acquisition System

3.3.3 Instrumentation Calibration

All thermocouple devices were calibrated before and after wheel instrumentation and before each test day began. The initial calibration procedure employed a portable heat source to generate known temperatures near the thermocouples while the computer recorded the thermocouple response. Results of this procedure are presented in Appendix I. Pre-test calibration consisted of verifying that each thermocouple responded to a temperature rise using the heat source, ensuring system integrity, and measuring the tread wear on the test wheels to determine each thermocouple's depth beneath the tread surface. The speed signal was calibrated by performing a measured mile test. Mile posts were recorded in the data stream using the event marker channel as the train traveled at a constant speed. A comparison was made between the train speedometer and the calculated speed based on the number of samples collected between the mile post markers in the data file. All pressure signals were calibrated against train gages.

The accuracy of the thermo-plug, plate thermocouples, and hand-held pyrometer temperature measurements is estimated to be +/- 10%. This estimate is based on thermocouple tolerances, limitations of material machining precision, data acquisition equipment errors, as well as thermal inconsistencies introduced to the wheels by the installation of the thermo-plug

assemblies. The equipment used throughout the data acquisition system was of the highest quality obtainable and was rigorously tested prior to the start of the test procedure.

4. TEST RESULTS AND OBSERVATIONS

4.1 OVERALL RESULTS

The NJT Operational Field Test succeeded in satisfying its objectives. The instrumentation system was able to measure the thermal energy transferred to the wheels under stop-braking conditions and these measurements were of sufficient resolution to reveal the thermal gradient that existed within the wheel rims. The test scenarios were adequate to thermally exercise the wheels in an attempt to generate in-service thermal conditions. In fact, during the car inspection after the first night of testing, two 0.5" long cracks were discovered on the tread surface of test wheel #L2. These cracks were determined to be thermally induced and were identical to the type of cracks that have been found on revenue wheels at NJT.

Furthermore, the instrumentation in and on the wheels was extremely durable. Only one thermo-plug (wheel #L1, position #3) was damaged, and this damage occurred while moving the wheel in the wheel shop area during the instrumentation procedure. Unfortunately, the damage was discovered too late in the instrumentation process to substitute the spare, instrumented wheel and still remain within the test schedule window. Instrumentation durability enabled many data runs to be performed, enough to satisfy the interests of all parties involved in the exercise. As stated in the introduction, the data gathered during this test were utilized for comparison with thermal model calculations and analysis performed at VNTSC.

The infrared thermal imaging and hand-pyrometer measurements of wheel temperatures were also successful. The thermal imaging procedure was able to provide surface temperature data from the test wheels and the test consist as well as from revenue trains. Pyrometer measurements helped to corroborate the results of the test wheel thermal imaging and to provide insight into the thermal state of wheel surfaces that the imaging equipment could not readily view. The detailed thermal imaging results are contained in Appendix III.

Graphs illustrating all the raw data from a total of 28 data files are included in Appendix II of this report. The test results and observations outlined in this section of the report will be limited to those which describe general trends observed in the data during acquisition and while processing the final data graphs.

4.2 WHEEL TEMPERATURE DATA

4.2.1 Temperature Measurement Locations

After the thermo-plugs were pressed into the wheel rims, precise measurements of thermocouple positions were made using a specially design measurement fixture (see Appendix I). The fixture was designed to allow depth measurements of the top of the thermo-plug relative to the wheel rim, thus assuring accurate measurements of the thermocouple position after wheel wear had occurred. The fixture used hardened steel pins located in the front and back rim faces of the wheels as locating devices and to suspend the fixture above the tread surface. Measurements were made from the fixture to the top of each thermo-plug using a depth micrometer. Little rim wear was experienced during this test because of the relatively low number of miles traveled. Measurements revealed a net rim wear of less than 0.0015" during the entire test and, therefore, the thermocouple radial positions were considered unchanged from the measurements listed in Figure 5. Figure 9 documents the net change in thermocouple positions during the test. The discontinuity of the measurement at position #6 was attributed to measurement error.

POSITION #	BEFORE TEST	AFTER TEST	NET CHANGE
3	1.653"	1.654"	+.001"
4	1.651"	1.652"	+.001"
6	1.659"	1.656"	-.003"
7	1.655"	1.655"	.000"

Figure 9 Thermo-plug Position Measurements

4.2.2 Typical Data Pattern

Graph 1 shows the results from a typical braking event during the test. A full-service brake application was made when the car reached 83 m.p.h., resulting in a steep rise in wheel rim temperatures. Wheel rim temperatures continue to rise throughout the braking event and reach a maximum value just after the brakes are released. At this point, wheel rim temperatures begin to decrease.

This thermal behavior pattern was witnessed during all braking event data runs regardless of braking rates, maximum vehicle speeds, or maximum temperatures recorded. Data trends observed throughout the test include:

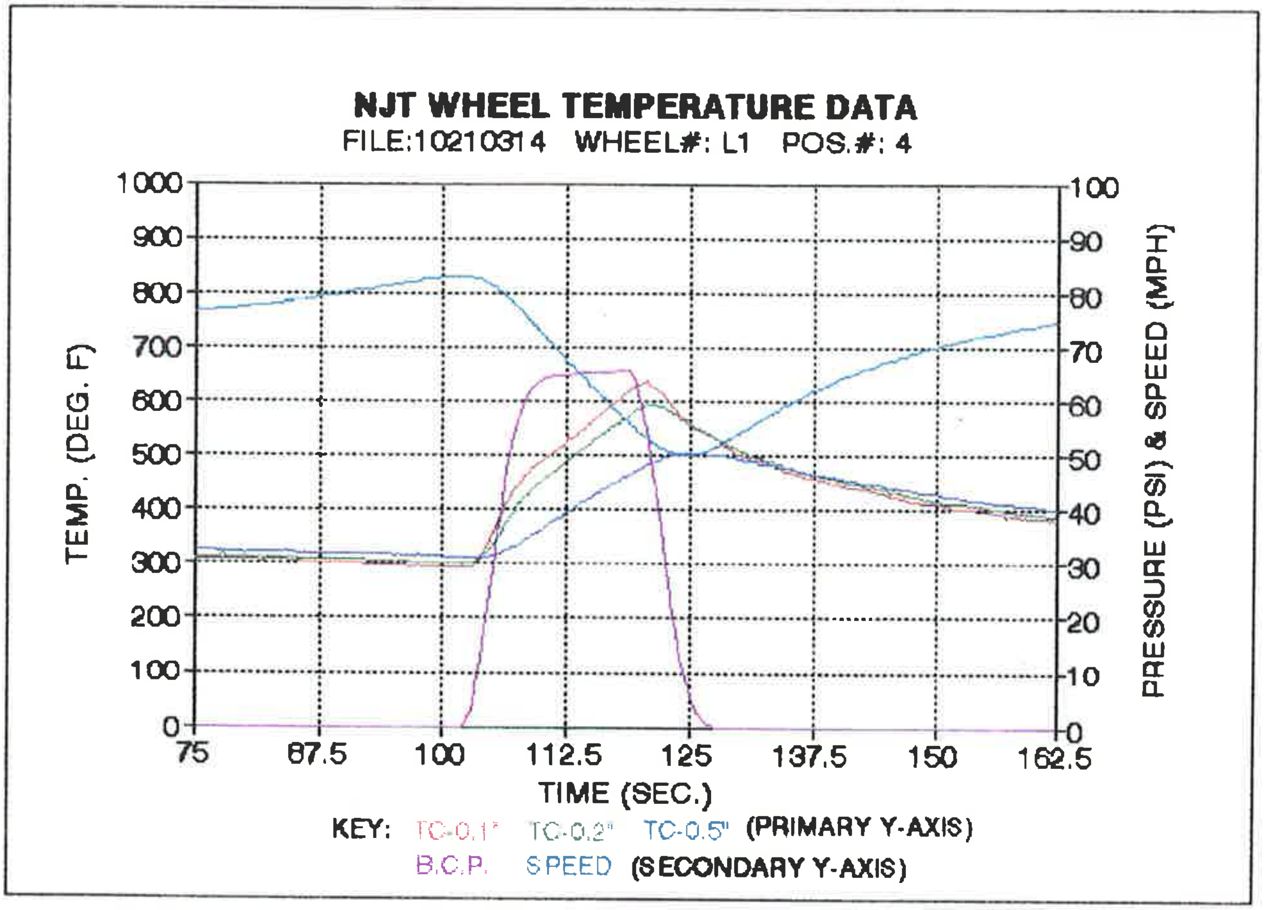
1. Temperature gradients were seen in all braking events and thermocouple temperature measurements closest to the tread surface were always higher than those deeper in the rim during braking.

2. During non-braking periods, temperatures deeper in the wheel rim were consistently higher than those closer to the tread surface.

3. Peak temperatures were recorded between 20 to 50 seconds after initial brake application.

4. Heating and cooling rates were always higher closer to the tread surface than deeper in the rim.

5. Fifty to 90 seconds were required for a thermocouple temperature measurement to drop to one-half of its peak rise after a braking event.

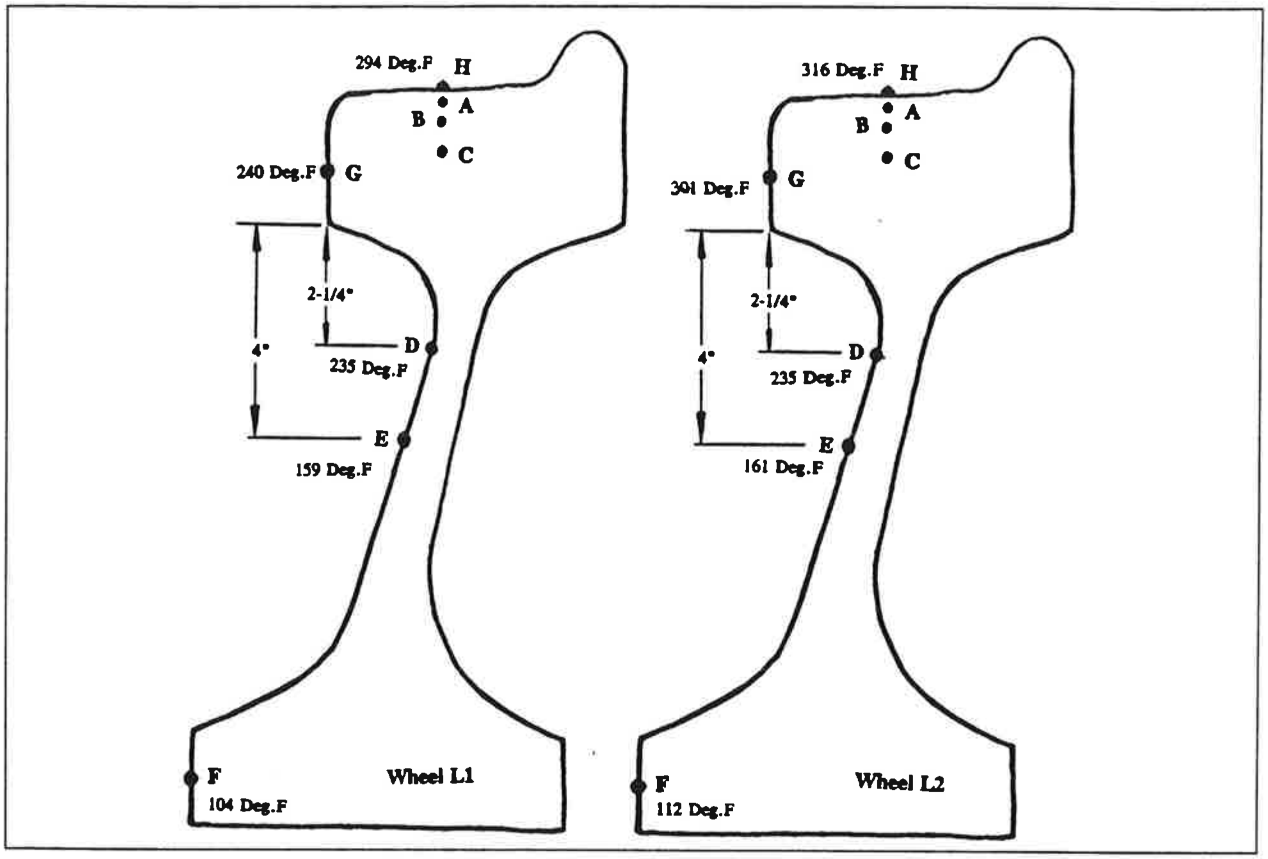


<u>Graph 1</u> Typical Data Pattern

6. Very little time delay was seen between initial brake application and rim temperature rise.

7. Calculations were made to determine the average thermal gradient between temperatures measured at 0.1" and 0.5" nominal depths, for each thermo-plug, from all test data files. Appendix II contains a chart which details this effort. The average thermal gradients for all data sets were:

POSITION #	GRADIENT (°F)
4	160.67
6	215.17
7	143.83



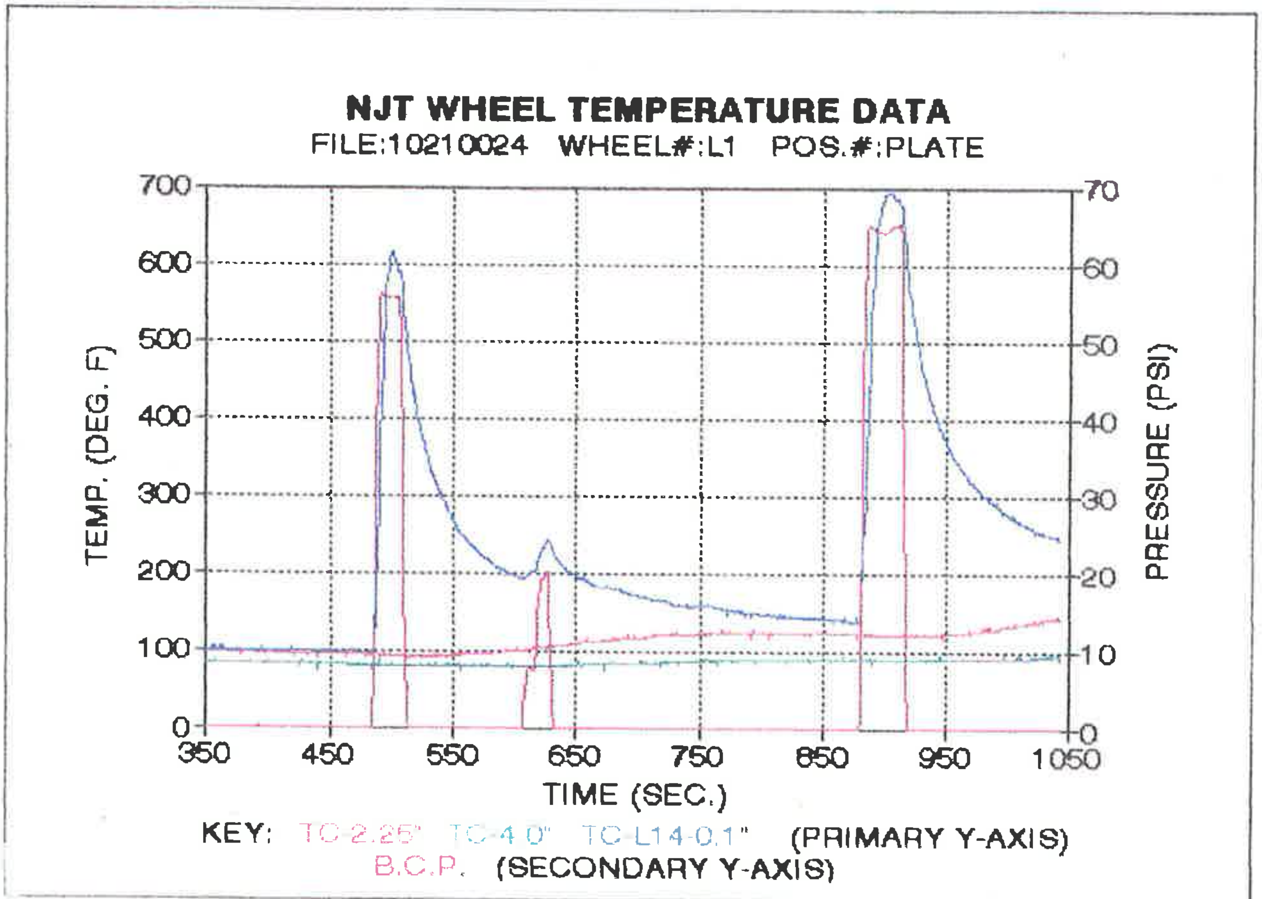
<u>Figure 10</u> **Tread and Plate Temperatures**

4.2.3 Tread and Plate Temperatures

Figure 10 shows a typical temperature pattern at various points on the tread and plate of the test wheels. Measurements made at the plate locations were recorded by the data acquisition system while the other measurements were made using the hand-held pyrometer and were taken approximately five to eight minutes after the plate temperatures were recorded, after the consist was stopped. Similar measurements were made at various times during the test procedure; and, while the value of the temperatures varied, their relative magnitudes remained consistent. The figure clearly illustrates the temperature distribution along the wheel surface, with the highest temperatures on the tread surface near the brake shoe contact area and progressively lower temperatures further from the wheel rim.

Graph 2 displays plate temperature changes during a typical data run and is consistent with plate reactions seen in other data files examined from this test. Plate reaction to brake shoe thermal input at the tread surface is delayed in proportion to the distance from the tread. The temperature curve at the 2.25" position exhibits a measurable, albeit small, change in slope approximately 100 seconds after the first brake application while the 4.0" position curve has no easily discernible slope change, instead it shows a small, gradual increase in temperature

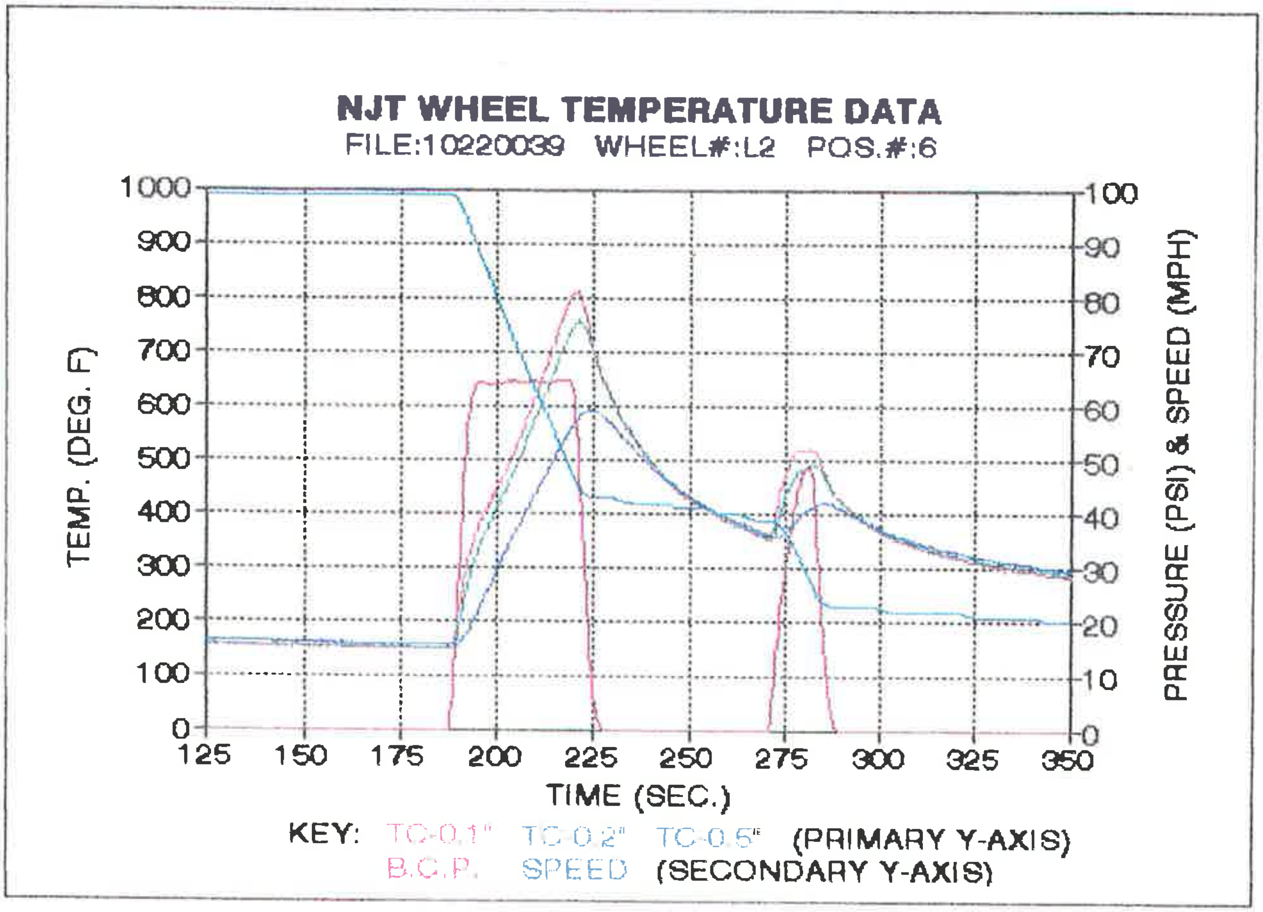
throughout the data run. These characteristics are indicative of plate thermal behavior seen throughout the test procedure.



Graph 2 **Plate Temperatures**

4.2.4 100 M.P.H. Braking Event

The main objective of the test procedure was to simulate braking events that are encountered during routine revenue service. NJT commuter trains operating on the Northeast Corridor attain speeds up to 100 m.p.h. and use full-service brake applications to slow the consist for station stops. Graph 3 illustrates temperature measurements recorded while performing such a maneuver. The temperature curves rise sharply as soon as the brake application is made, reach a peak value shortly after the brakes are released, and then rapidly descend. The temperature measured at the 0.1" deep position rises from 150 ^{0}F to a peak of 813 ^{0}F and the maximum thermal gradient between the 0.1" and 0.5" positions is 238 ^{0}F. Documentation of the maximum thermal gradients for each data file is provided in Appendix II.

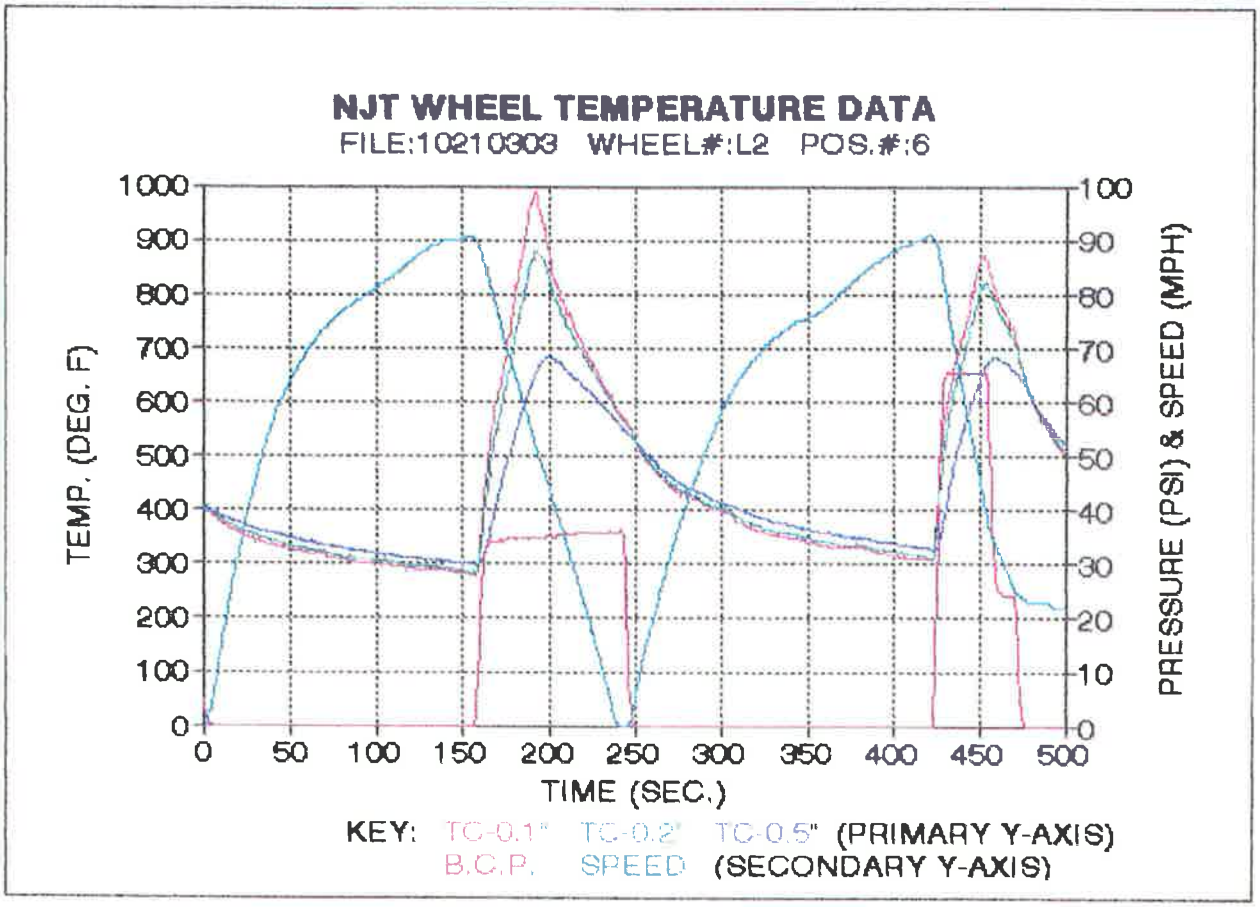


Graph 3 **100 M.P.H. Braking Event**

4.2.5 Highest Recorded Temperature

The highest temperature recorded during the entire test procedure was 991 ^{0}F, measured at position #6 on wheel #L2. Graph 4 displays the data from this run. Interestingly, this temperature was measured during a 90-to-0 m.p.h. test sequence using only 35 p.s.i. of brake cylinder pressure. Moreover, the next braking event documented in this graph was done at the same speed but with a full-service (65 p.s.i.) brake application and the peak temperature at the same measurement point was only 872 ^{0}F.

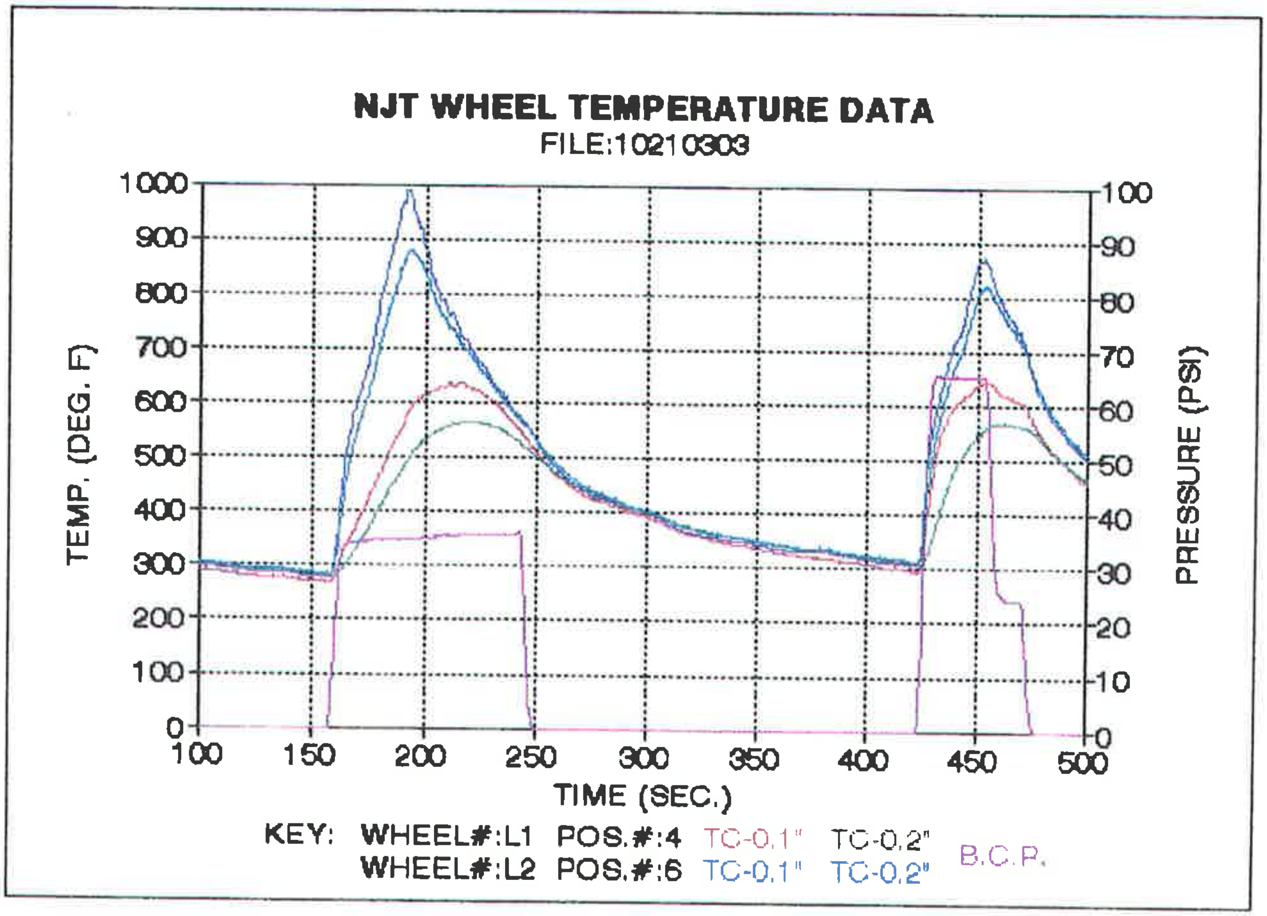
Further investigation of this first braking event revealed significant inconsistencies between the temperatures measured at position #7, 180 deg. from position #6, and from position #4 on wheel #L1. The peak values at these locations were 795 ^{0}F and 672 ^{0}F, respectively. Clearly there was an abnormality present during this run; this type of wheel-to-wheel and position-to-position deviation was not seen, with the same magnitude, during other data runs.



Graph 4 **Maximum Recorded Temperature**

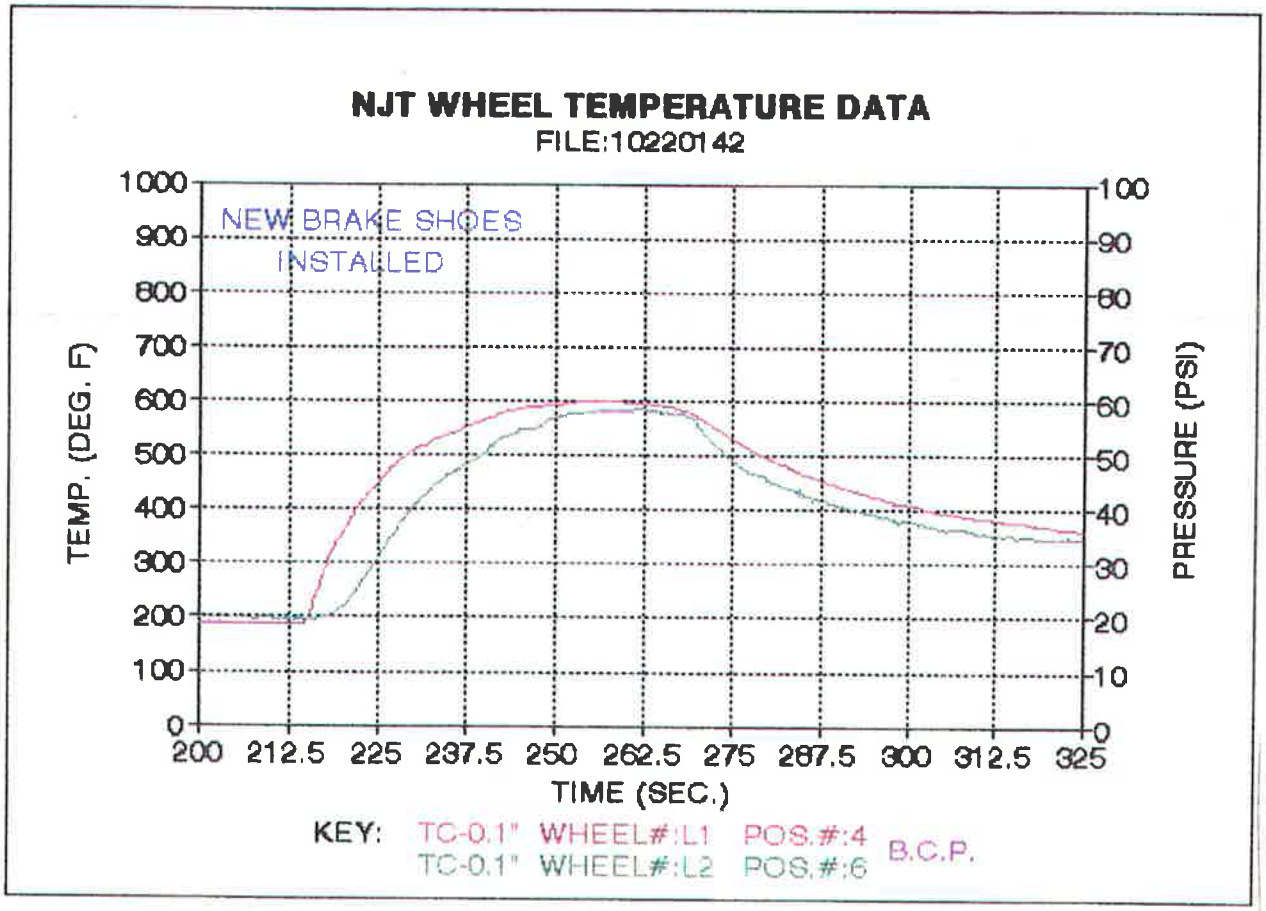
4.2.6 Temperature Differences

The discovery of significant temperature measurement differences at the three working thermo-plug locations led to further investigation of this phenomena. Peak temperature data averages from all 0.1" thermocouples show that position #6, with an average of 756 ^{0}F, was much higher than position #7 or #4, with averages of 669 ^{0}F and 645 ^{0}F, respectively. The Maximum Temperature Gradient Analysis chart in Appendix II contains the averaged data for all the data files. Graph 5 displays wheel-to-wheel temperature differences measured during the same data run. Many factors may be responsible for these measurement differences, including variations in thermo-plug response characteristics from plug to plug, minor depth inconsistencies between plugs in the wheel rims and between thermocouple positions within the thermo-plug assemblies, as well as variations in brake shoe friction coefficients between the two wheels.



<u>Graph 5</u> Wheel-to-Wheel Temperature Differences

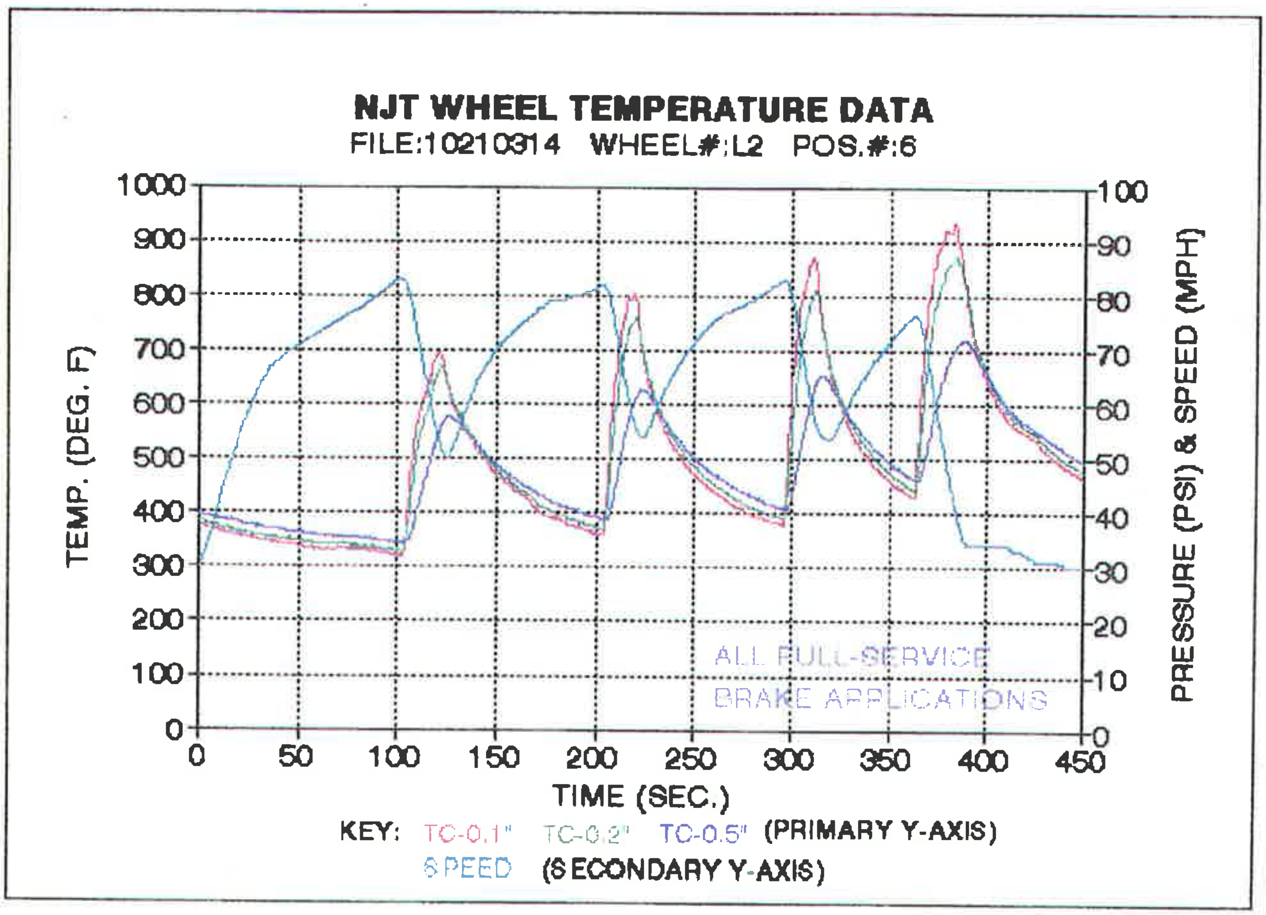
Graph 6 shows the effect of new brake shoe installation on wheel-to-wheel temperature measurements. Brake shoes at the test wheel locations at the start of the test procedure were in good, worn condition as described in Section 3.2. After a number of data runs were made with these shoes, the decision was made to replace the worn shoes with new ones; the motive being curiosity about wheel thermal behavior differences with new brake shoes installed. Temperature differences between the test wheels were dramatically reduced as the graph illustrates. However, analysis of subsequent data files revealed that the wheel-to-wheel temperature differences returned to the same magnitude as with the worn brake shoes after the new shoes began to wear.



Graph 6 New Brake Shoe Effects

4.2.7 Temperature Ratcheting

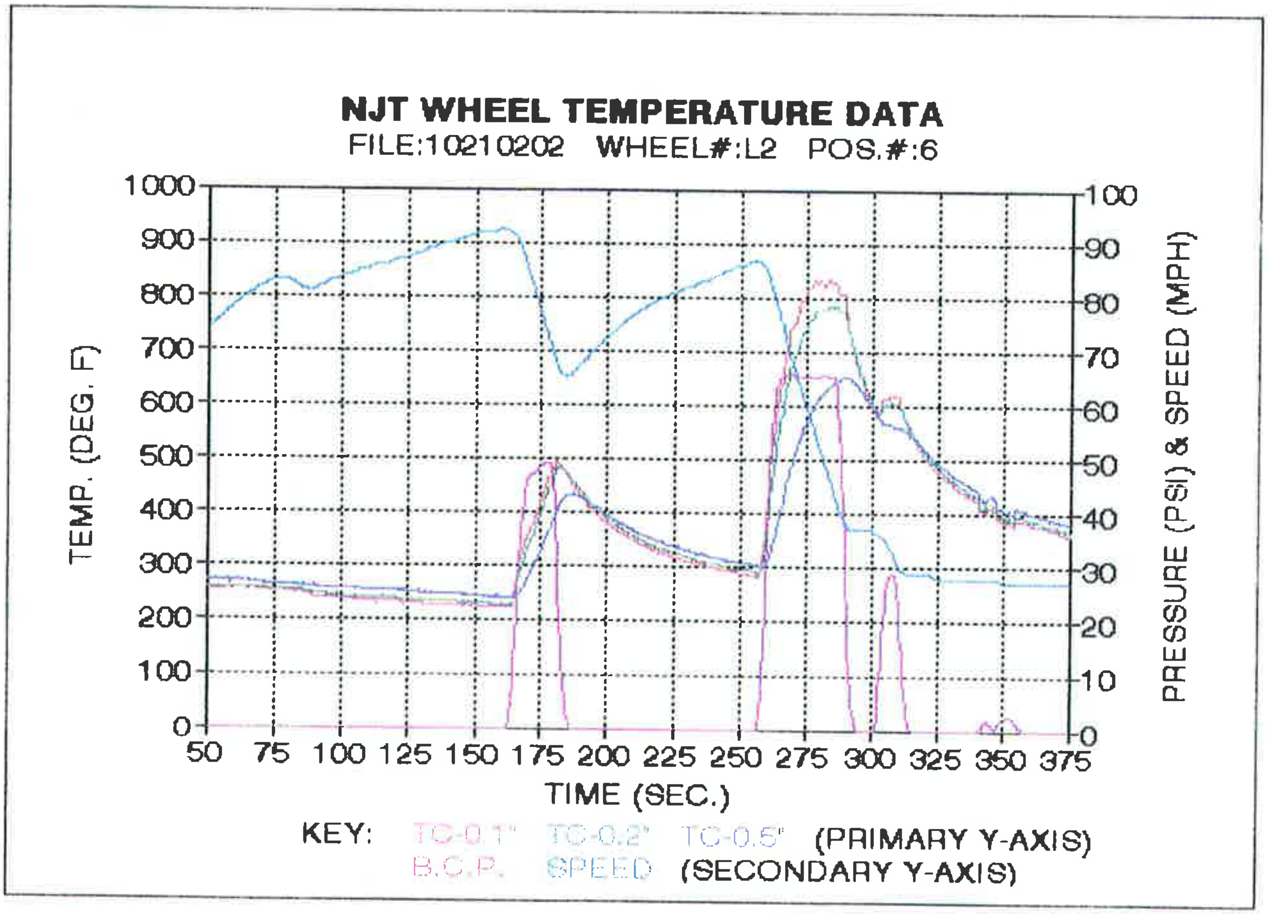
Trains running in commuter service on NJT undergo numerous, rapid acceleration and deceleration cycles in order to meet timetable requirements between their many station stops. The effect of these cycles on wheel temperatures was simulated during the test procedure by performing a series of rapid accelerations, to a predetermined velocity, followed by a deceleration to a predetermined speed using full-service braking with variable brake reductions. One such data run is illustrated in Graph 7. During this exercise, the test consist was cycled between 83 m.p.h. and 55 m.p.h., in rapid sequence, using a full-service brake application. The results of this test on wheel temperatures are quite clear. Maximum wheel rim temperatures, as well as rim thermal gradients during each braking cycle, display a measurable increase in magnitude after each braking event. The wheels do not have sufficient time to cool between brake applications causing wheel temperatures to "ratchet" upward.



Graph 7 Temperature Ratcheting

4.2.8 Brake Pressure Change Effects

Graph 8 reveals the effects of brake cylinder pressure variations on wheel rim temperatures. Two braking events from approximately the same initial velocity were performed using different brake pressures and duration. The effect of this procedure on wheel rim temperatures is clear. The graph shows a distinct relationship between brake cylinder pressure/duration and wheel rim temperatures; longer brake applications combined with higher brake pressures generate higher wheel temperatures than short duration, lower brake pressure events. This relationship also exists in other data files (see Appendix II).

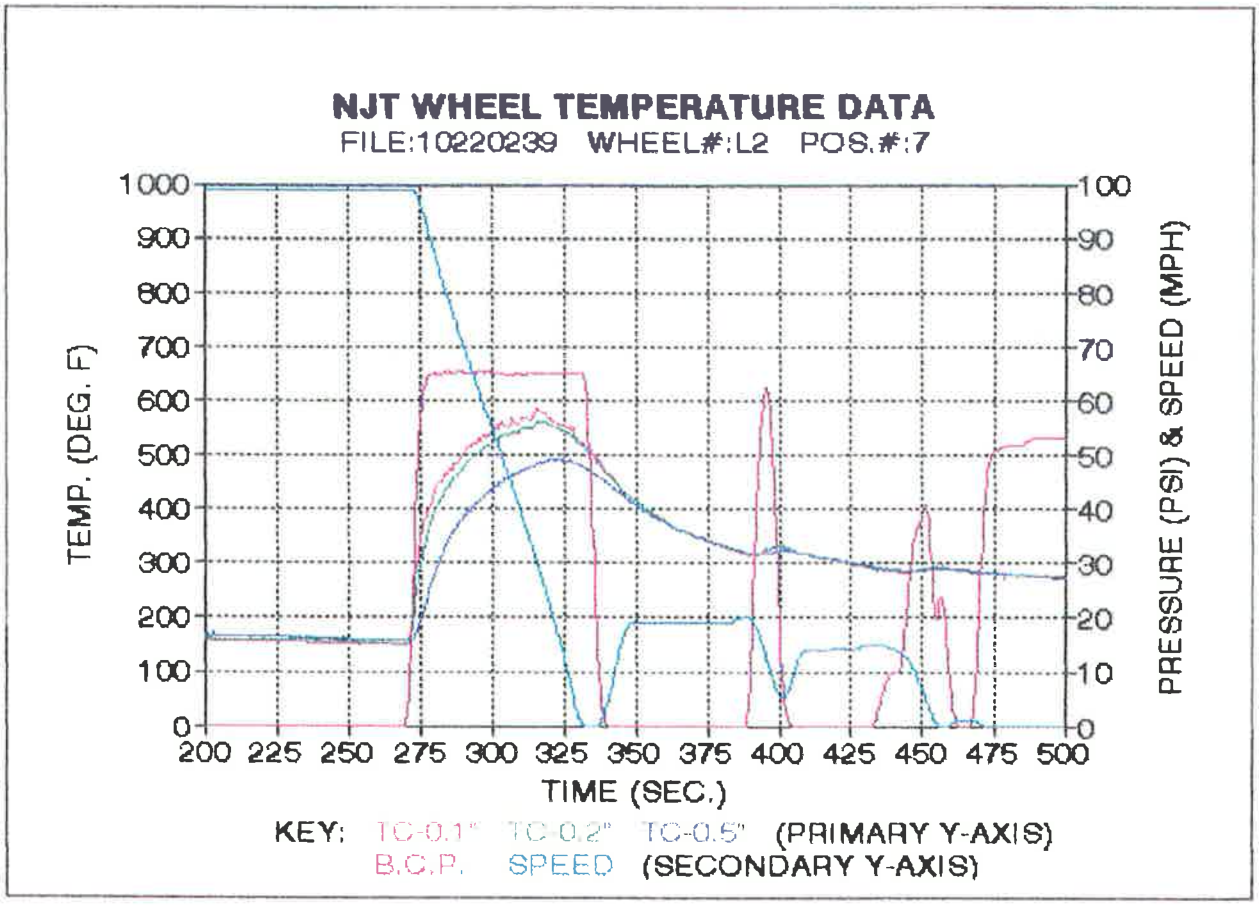


Graph 8 Brake Pressure Change Effects

4.3 INFRARED THERMAL IMAGING

Infrared thermal imaging services, provided by Baird Infrared, Inc., were performed on the second night of the field test. Test train imaging was conducted at the Princeton Junction Station, while revenue train inspection was done both here and at the Metropark Station. All raw data was recorded on VHS videotape and then later processed to include numeric temperature measurement annotation using an Inframetrics ThermaGRAM computer imaging processing system. This system produces "false color" images in which the various colors indicate distinct temperature ranges. Logistic difficulties trying to capture clear images of a moving specimen resulted in incomplete test data in some cases. However, the wheel temperature data that were taken proved to be useful in assessing wheel surface temperature variations. An average emissivity of 0.87 (entire wheel) was calculated for the test wheels and this value was used for all subsequent thermal measurements on both the test train as well as the revenue trains. Unfortunately, the thermal imaging technique is highly sensitive to object emissivity and this value may be incorrect for different wheels. Baird, Inc. estimates the accuracy of their temperature measurements to be +/- 20%. More accurate results would have been possible if emissivities were calculated for every recorded wheel, but this was not possible. Simultaneous, comparative

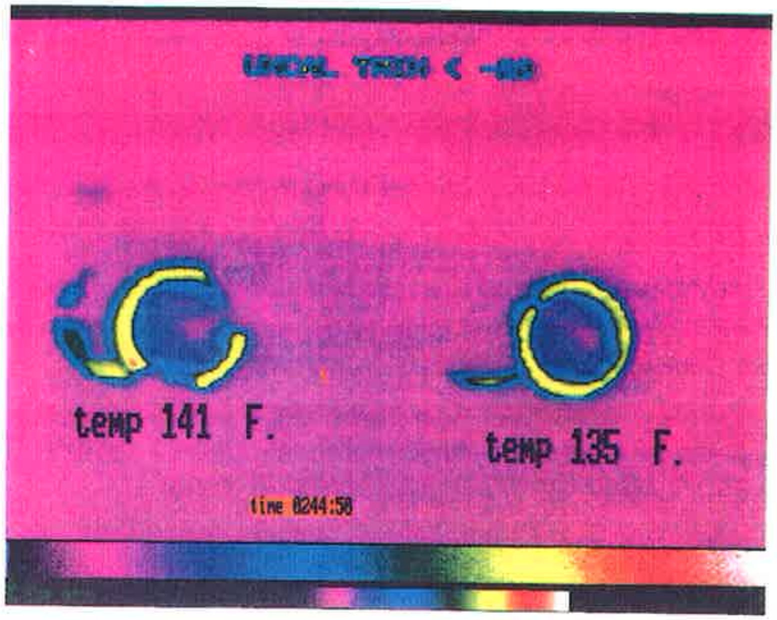
temperature measurements using the hand-held pyrometer helped to validate the accuracy of the thermal imaging technique on the test wheels. Measurements differed by only a few degrees between the two techniques. Fortunately, the thermocouple instrumentation on the test wheels was sufficiently robust to provide quality data throughout the test procedure, and infrared thermal imaging was not needed as a primary source of wheel temperature data.



Graph 9 Thermocouple Data

The objectives of the thermal imaging portion of the field test (Section 2.5.1) were accomplished during the test procedure. The results satisfying the first objective, quantifying the relationship between internal and surface wheel temperatures, are illustrated in Graph 9 and Figure 11; both report wheel temperatures on the test train at the same moment in time. Thermocouple measured internal wheel temperatures, Graph 9, after the consist had stopped at Princeton Junction, are around 275 deg. F (Time 475 - 500 sec.). Figure 11, thermal imaging data taken at the same time, shows an average surface wheel temperature of around 140 deg. F. Unfortunately, the test train was traveling east bound at the time these images were recorded and, therefore, the primary images in the figure are of the wheels on the opposite side of the train from the test wheels. The test wheels are partially visible (rear rim faces) in the background and are seen to be at the same temperature range as the primary wheels. Annotated data is available for all the wheels on this side of the test train (see Appendix III) and reveals an order-of-magnitude similarity between all wheel temperatures. The mean temperature for all 20 wheels measured on

this side of the consist is 128 ^{0}F and the standard deviation between this data set, using the population standard deviation method, is 17.1 ^{0}F.



<u>Figure 11</u> Thermal Imaging Data

Thermal imaging was also able to provide quantitative information regarding the surface temperatures of wheels on other trains on the railroad that night, satisfying the second test objective. Temperature data from a NJT revenue train (included in Appendix III) enables a comparison to be made between the test consist and normal revenue traffic. The data from this eleven car, eastbound train reveals a mean wheel temperature of 166 ^{0}F with a standard deviation between wheels of 26.9 ^{0}F, values that are quite similar to those measured on the test consist. Limited data is also available on an eastbound Amtrak train. Wheel temperatures on this train were consistent with those measured on the test consist and other revenue trains.

In conclusion, infrared thermal imaging appears to be a useful method of determining in-service wheel temperatures. It provided valuable information on the thermal behavior of other, non-instrumented, wheels on the test consist, as well as insight into the thermal environment of other wheels on different consists. Given the sensitivity of thermal imaging to object emissivity, and its direct relationship to measurement accuracy, this measurement technique appears best suited to analyzing limited numbers of wheels, allowing accurate emissivity measurements to be made prior to thermal measurement. Regardless of absolute accuracy concerns, the method was extremely useful for making the general comparisons between wheels and trains, thus satisfying the test objectives.

APPENDIX I

THERMO-PLUG DESIGN AND IMPLEMENTATION

TABLE of CONTENTS

1. INTRODUCTION

The purpose of this section of the report is to provide technical information regarding the design and implementation of some of the specialized equipment used during the New Jersey Transit Operational Field Test. Equipment to be detailed include the thermo-plug assembly, the measurement jig, and railroad wheel modifications made for the test procedure.

2. THERMO-PLUG

The thermo-plug was developed in response to the specific requirements of the temperature measurement environment dictated by the field test objectives. Accurate temperature measurements were required at precisely defined locations inside the wheel rim under the tread surface while operating in a consist in simulated revenue service. These requirements placed severe constraints on the mechanical design of the measurement system. First, thermal response had to be optimized. Second, the thermocouples had to be electrically isolated from the wheel in order to avoid electrical interference in the signal path, and lastly, the measurement device had to be strong enough to withstand the high mechanical stresses that it would encounter in simulated service operations.

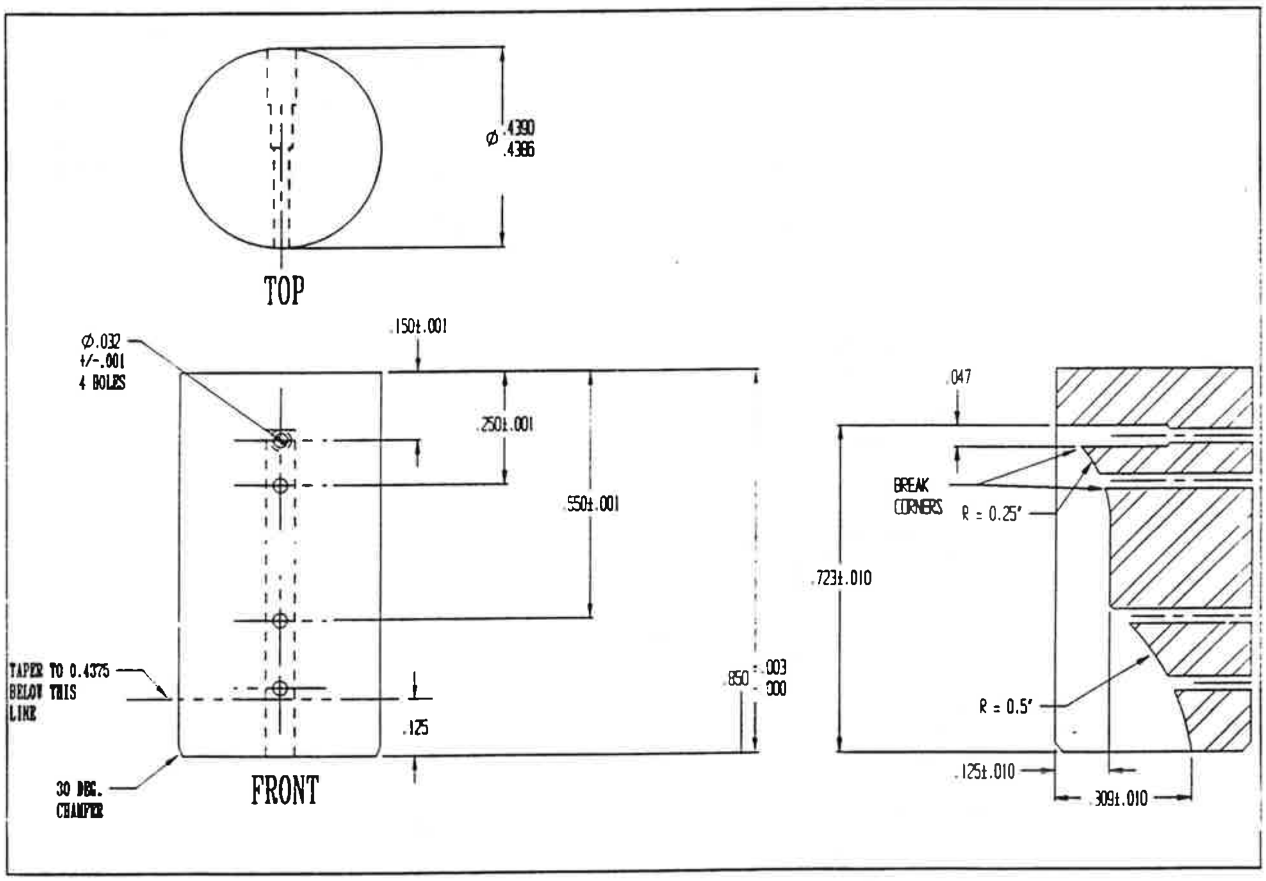


Figure 1 Thermo-Plug Design

The final design for the thermo-plug assembly was developed after numerous alternatives were analyzed. A detailed drawing of the assembly appears in Figure 1. This design proved to be a complete success during the test procedure. It was able to survive the harsh electrical and mechanical environment while providing clean, accurate temperature measurement data throughout the test.

3. MEASUREMENT JIG

The measurement jig illustrated in Figure 2 was designed to facilitate accurate measurement of thermocouple position, relative to the wheel tread surface, after the thermo-plug assembly was installed in the wheel. Also, periodic position measurements were to be made during the test procedure to account for tread wear during the test. The jig uses hardened steel dowel pins installed in the wheel rim, to locate the fixture relative to the tread surface. Once in position, a standard depth micrometer is placed on the top of the jig and a depth measurement is made to the top of the thermo-plug imbedded in the tread. Knowing the "as-machined" location of the thermocouples in the plug, thermo-plug/wheel tread wear was tracked throughout the installation and test procedure.

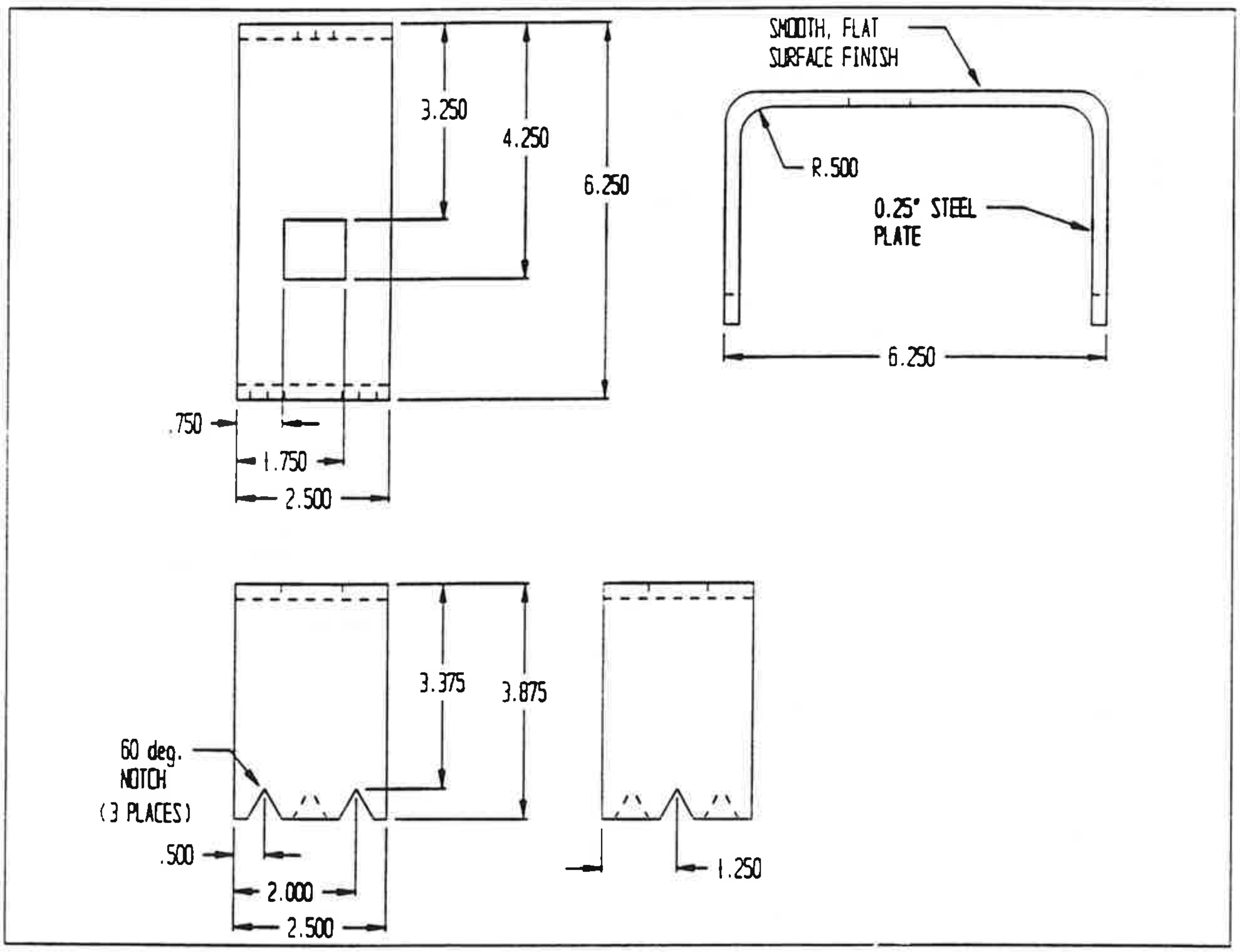


Figure 2 Measurement Jig

4. WHEEL MODIFICATIONS

Modifications made to the test wheels are illustrated in Figures 3, 4, and 5. These modifications were made to accommodate the thermo-plug assembly and thermocouple wires, and the steel dowel pins needed for the location measurement procedure.

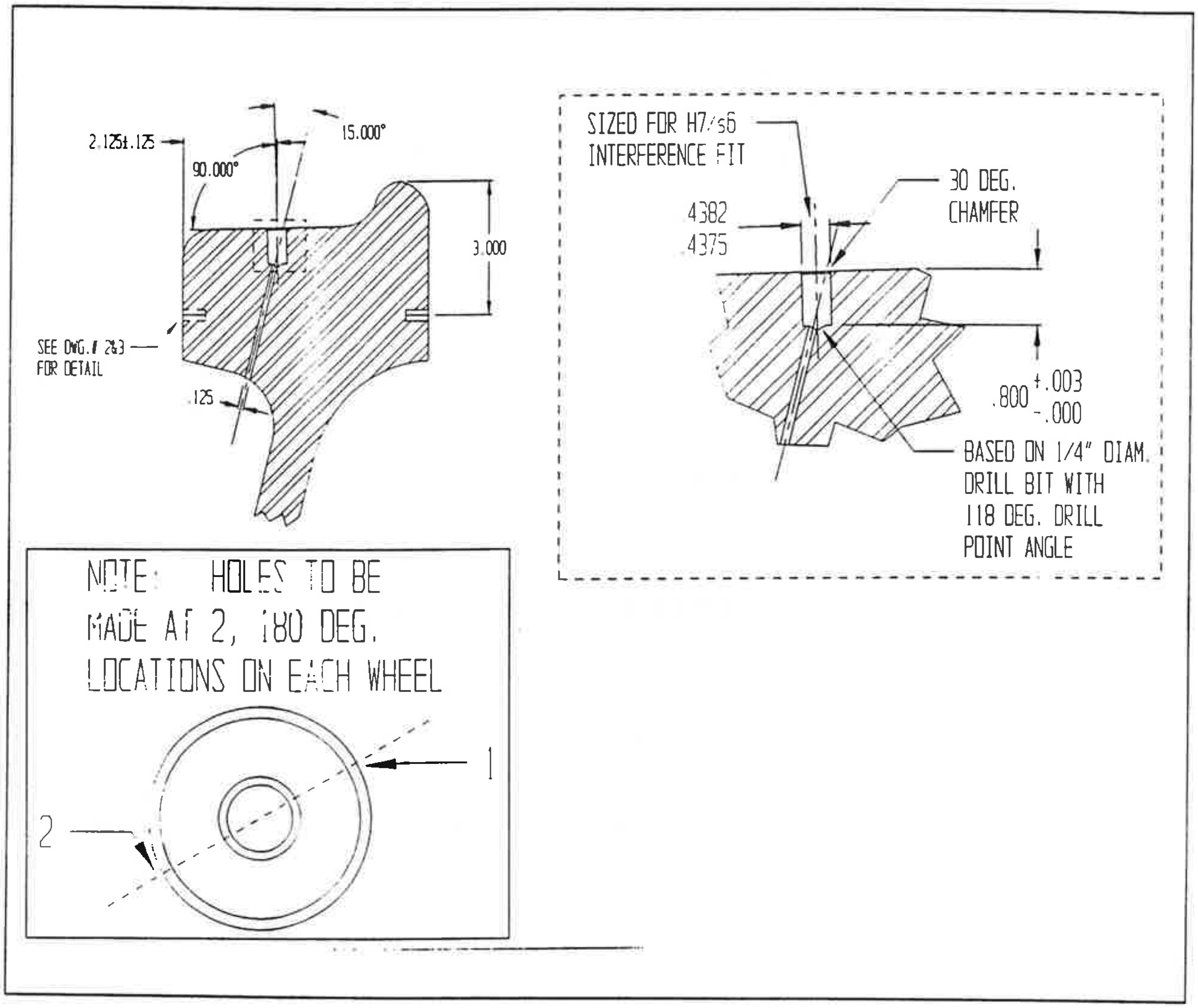


Figure 3 **Wheel Modifications 1**

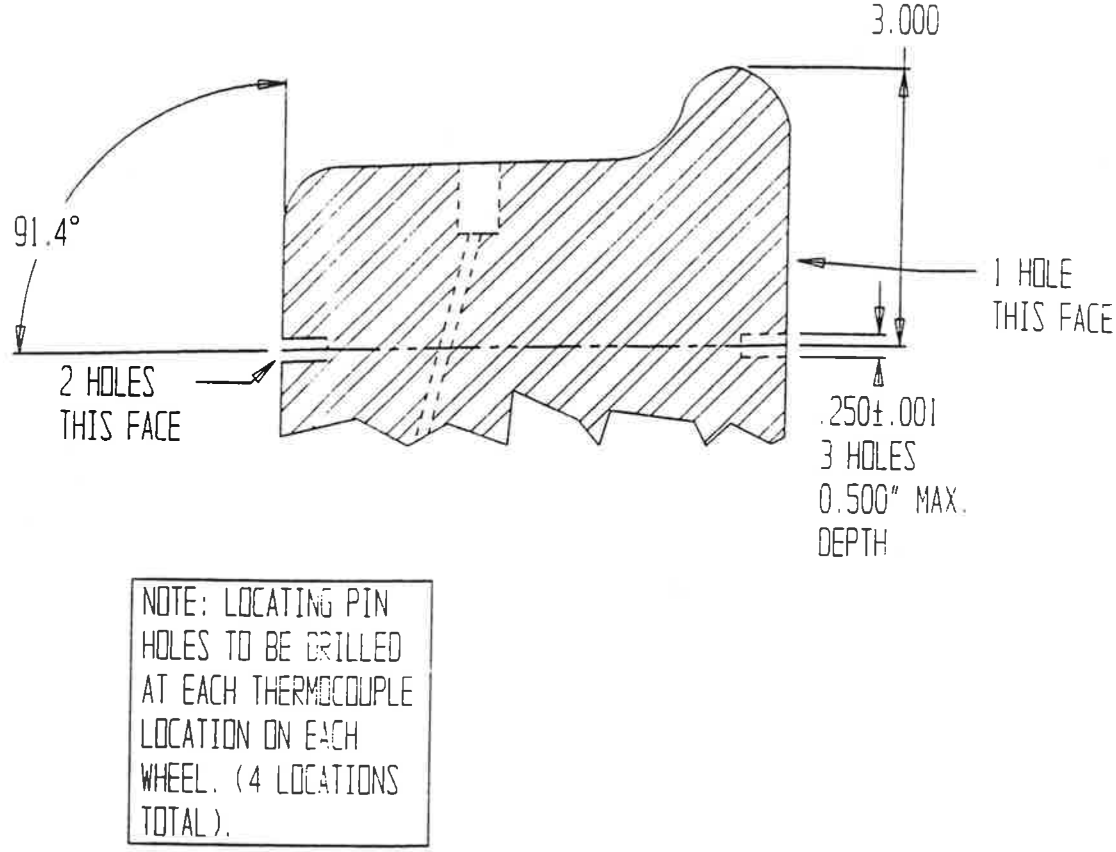


Figure 4 Wheel Modifications 2

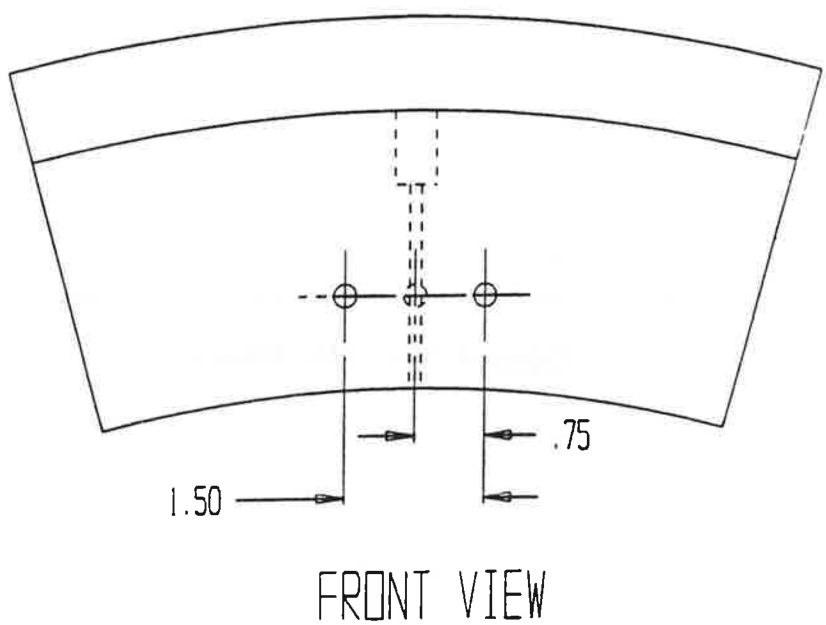


Figure 5 Wheel Modifications 3

5. THERMO-PLUG IMPLEMENTATION

Before instrumenting the test wheels, a prototype thermo-plug was produced in order to fully test the device to confirm that it would perform as designed. The following test plan was developed for the implementation test procedure.

<u>OBJECTIVE</u>: The objectives of the thermo-plug implementation exercise are:

1. Verify that the thermocouple response time meets requirements.
2. Verify that the thermo-plug will produce a clearly discernible temperature gradient, and test the survivability of the thermo-plug under thermal shock-loading conditions.
3. Verify that the thermocouples are electrically isolated from each other and from the thermo-plug.
4. Verify that the thermo-plug is working after installation in the wheel. Check the consistency of plug installation (plug-to-plug).
5. Accurately locate each thermocouple in the plug, relative to the tread surface of the wheel, after initial contouring.

Each thermo-plug will be tested individually.

The following steps outline the procedure for meeting the stated objectives.

STEP 1: THERMOCOUPLE RESPONSE TEST

PURPOSE: The purpose of this test is to measure the response of the thermocouples inside in the plug before the plug is pressed into the wheel. The test should be performed on one or two representative thermo-plugs.

PROCEDURE: A thermo-plug is stabilized at ambient temperature (measured) and then placed in a pot of boiling water (temp. monitored). The thermocouple response is measured over time and recorded until it reaches 90% of the water temperature. This procedure is performed three times for each thermo-plug tested.

ASSUMPTIONS:

1. All thermal boundary conditions are equal for each thermocouple.
2. The thermo-plug is exposed to an isothermal environment.
3. All thermocouples in the plug have equal response characteristics.

OUTPUT: The output of this step is a graph comparing Temperature versus Time for each thermocouple.

ANTICIPATED RESULTS: If the original test assumptions are valid, the Temperature versus Time curves for each thermocouple should be very similar. From these graphs, the thermal response of each thermocouple can be calculated as the slope of their response curves. The response rate should be close to 34 deg./sec. for each thermocouple. If the response is significantly less than this value, a faster responding thermocouple may be needed for the wheel test.

STEP 2: THERMAL GRADIENT AND SURVIVABILITY TEST

PURPOSE: The purpose of this test is to determine if the response of each thermocouple within the plug is clearly defined when the thermo-plug is exposed to a thermal gradient. This test will also evaluate the survivability of the thermo-plug under thermal shock-loading conditions.

PROCEDURE: The procedure for this test includes installing the thermo-plug into a pre-drilled thru-hole in a steel disk and then placing this assembly in contact with a heated copper disk and recording the response from the thermocouples in the plug. The detailed test procedure is as follows:

1. The thermo-plug is pressed into the steel disk (slip-fit, thermal grease applied), connected to the instrumentation, and the assembly is allowed to stabilize at ambient temperature.
2. The copper disk is heated to approximately 1000 deg. F and placed in contact with the steel disk.
3. The thermocouple response is measured for 10 seconds.
4. The steel disk is allowed to return to ambient temperature.
5. The procedure is repeated twice for each thermo-plug.

OUTPUT: The output of each trial of this step is a graph comparing Temperature versus Time for each thermocouple within the plug.

ANTICIPATED RESULTS: This step of the experiment attempts to determine the resolution of the thermal response of each thermocouple in the plug. If the thermocouple junctions inside the plug are sufficiently isolated from each other, the output graph should yield three distinct curves, one for each thermocouple. Specifically, the test will determine if delta T is discernible from the output graphs. If the three curves are not distinct (delta T is not measurable), the design of the thermo-plug and/or the accompanying instrumentation must be altered. The thermocouple junctions may be too close or not well insulated and are acting as one junction, and/or the instrumentation sample rate may be too slow to reveal the three independent curves.

The survivability of the thermo-plug is revealed as a by-product of this step. The plug is subjected to thermal shock-loading each time it is placed in contact with the copper disk. If the thermocouples can return to ambient temperature after each encounter, they should be sufficiently robust, thermally, for the wheel temperature test.

STEP 3: ELECTRICAL ISOLATION TEST

PURPOSE: The purpose of this test is to verify that the thermocouples are electrically isolated from each other and from the thermo-plug after undergoing thermal shock-loading.

PROCEDURE: The procedure for the electrical isolation test is comprised of three parts.

PART 1: Resistance test between adjacent thermocouples within the thermo-plug. An ohmmeter is connected between the conductive wires of two thermocouples and resistance is measured. Any measurement of less than 10M ohms between thermocouples indicates a lack of complete electrical isolation and the thermo-plug fails.

PART 2: Resistance test between thermocouple conductors and thermo-plug housing. Identical to Part 1 but measurement is made between thermocouple and thermo-plug. Again, any resistance less than 10M ohms indicates isolation failure.

PART 3: Electrical conductivity test. A 240VAC source is connected to the two conductors of each thermocouple and an ammeter is placed in the circuit. A current measurement greater than 0 amperes indicates damage to the thermocouple connectors and the thermo-plug fails.

STEP 4: POST-INSTALLATION CHECK

PURPOSE: The purpose of this step is to ensure that the thermocouples are functioning after the plug is installed into the wheel, and to provide a consistency-of-installation check between all four plugs.

PROCEDURE: After the plug is installed in the wheel, a torch flame is directed onto the plug and the area is heated until the thermocouple response is detected. The process is repeated for each thermo-plug.

OUTPUT: A graph like that produced in Step 2 will be made for each plug.

ANTICIPATED RESULTS: The output graphs should be very similar to those in Step 2. Each thermocouple's response should be clearly defined from the others in the plug. If not, damage to the plug has resulted from installation in the wheel and the plug must be replaced. Also, each plug should have similar response characteristics, indicating a consistent machining and installation process from plug to plug. Any significant response deviation between the plugs should be noted and quantified for later analysis of the experimental results.

STEP 5: THERMOCOUPLE POSITION IN WHEEL

PURPOSE: The purpose of this step is to mechanically locate each thermocouple, within a plug, with respect to the wheel tread. This step must be done after the plug is initially contoured to the shape of the tread and for any subsequent testing after the wheel tread has been service-worn.

PROCEDURE: The measurement apparatus is illustrated in Figure 6, the measurement procedure is as follows:

Before wheel contouring:

1. Insert the locating pins into the pre-drilled holes on the front and back rim faces of the wheel.
2. Position the measurement frame on the pins.
3. Measure and record the distance from the frame to the top of the thermo-plug using the depth micrometer.

After wheel contouring:

1. Repeat the above procedure.
2. Compare the results of each measurement. The difference between the first and second measurement is the net change in plug height. Knowing the "as machined" dimensions of the thermo-plug, calculate the position of each thermocouple in the plug.

ANTICIPATED RESULTS: The location of each thermocouple in the plug should be known to within +/-0.005". This is based on the dimensional accuracy of the plug, the uncertainty in the location of the thermocouple junction within the probe, the precision of the measurement jig, and the micrometer accuracy.

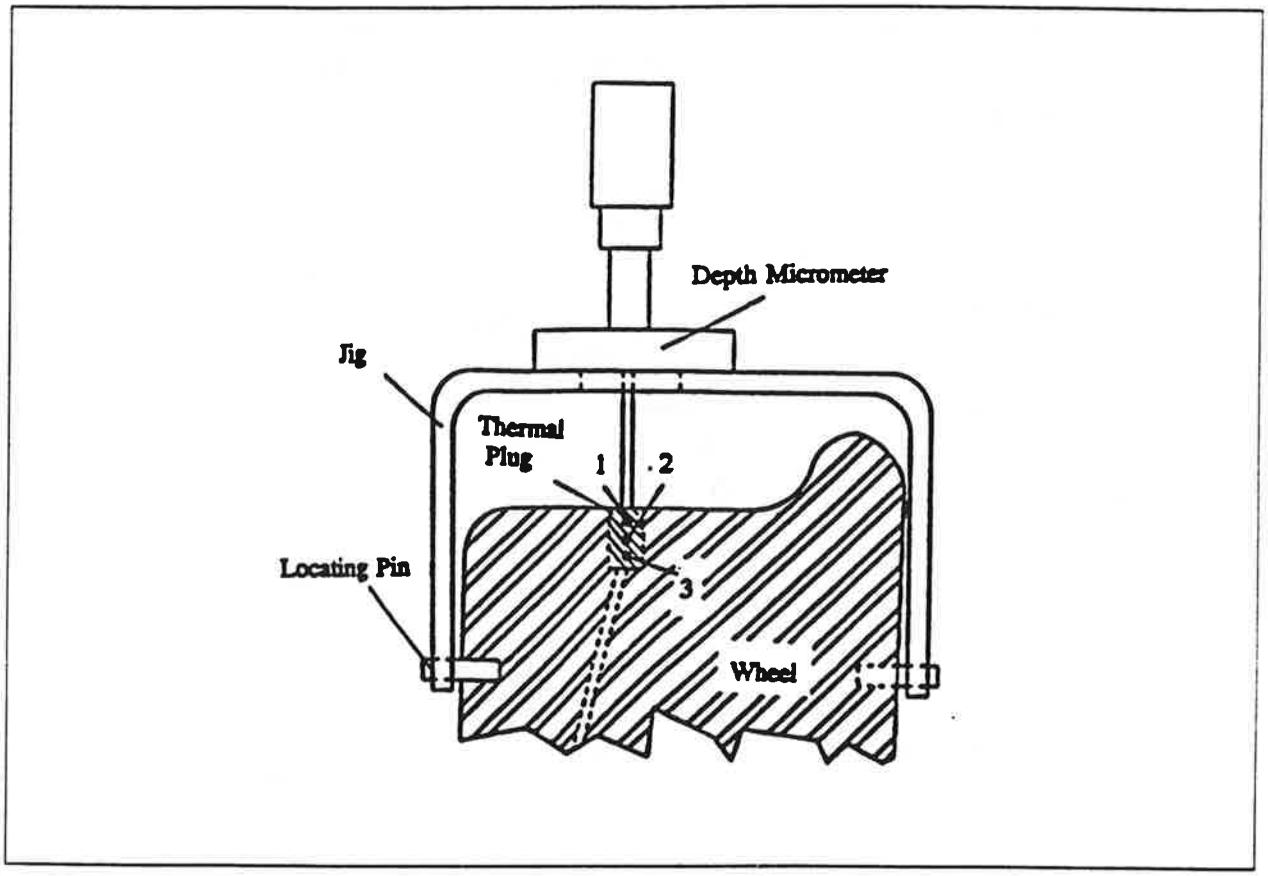
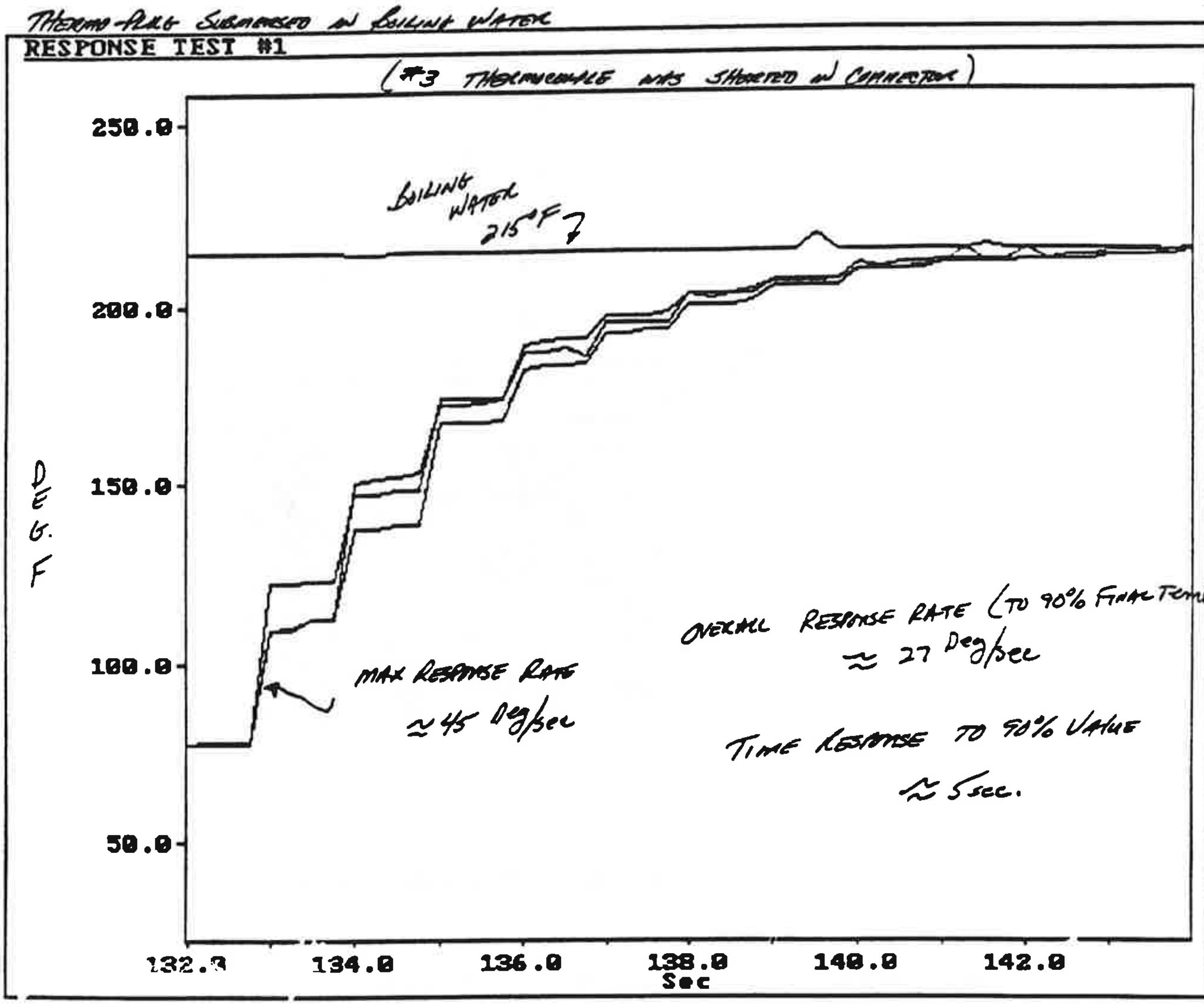


Figure 6 Depth Measurement Diagram

6. IMPLEMENTATION PROCEDURE RESULTS

6.1 THERMAL RESPONSE TEST

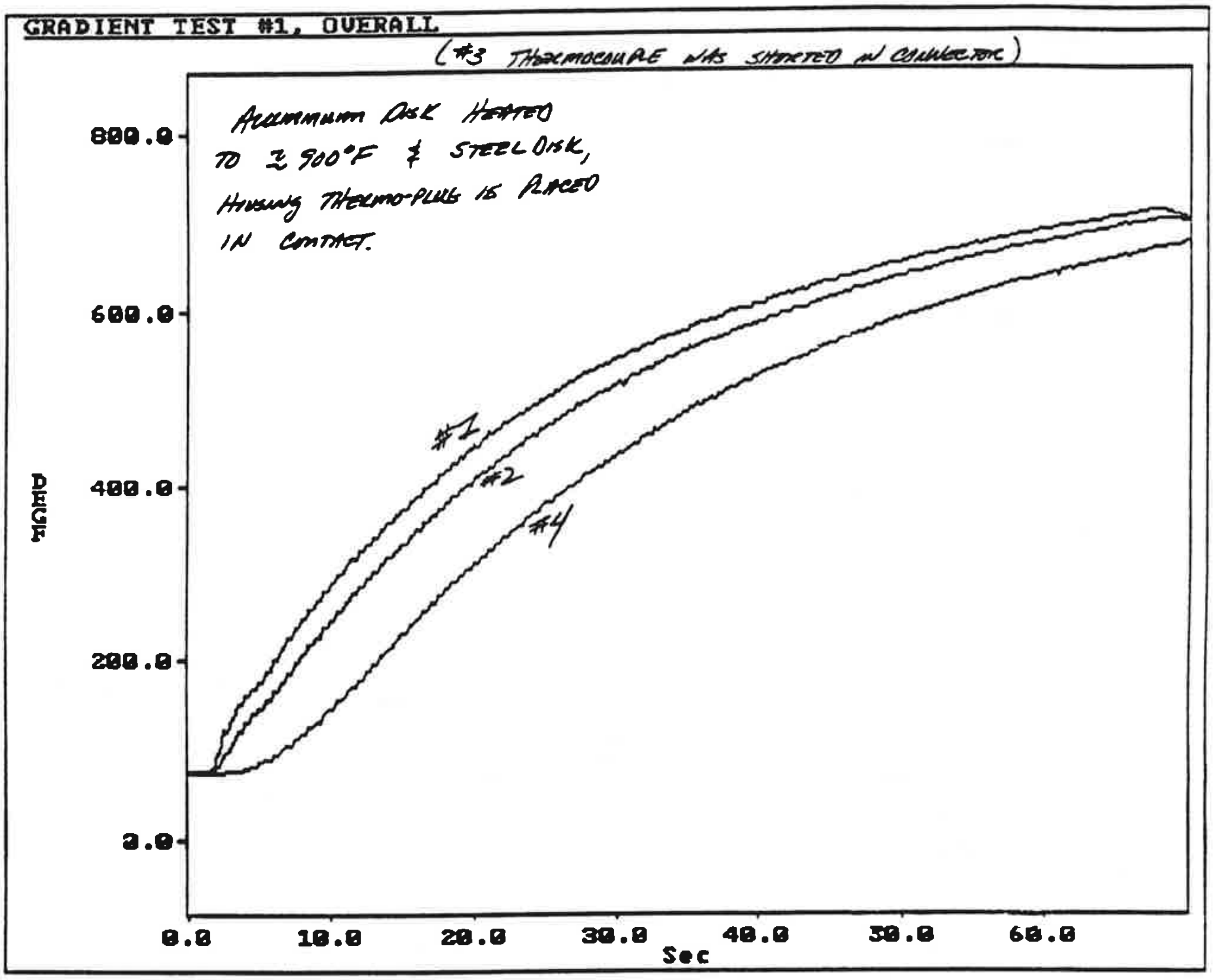
Graph 1 shows the results from the thermal response test. The actual test results were quite close to the anticipated results listed in the test plan. The response curves for each thermocouple within the thermo-plug were quite similar, and the thermal response of the assembly was close to the anticipated rate of 34 deg./sec. Note: The "step" response indicated in this graph was an artifact induced by a non-uniform sample rate in the data collection system. This sample rate problem was corrected before the start of the actual test.



Graph 1 Thermocouple Response

6.2 THERMAL GRADIENT AND SURVIVABILITY TESTS

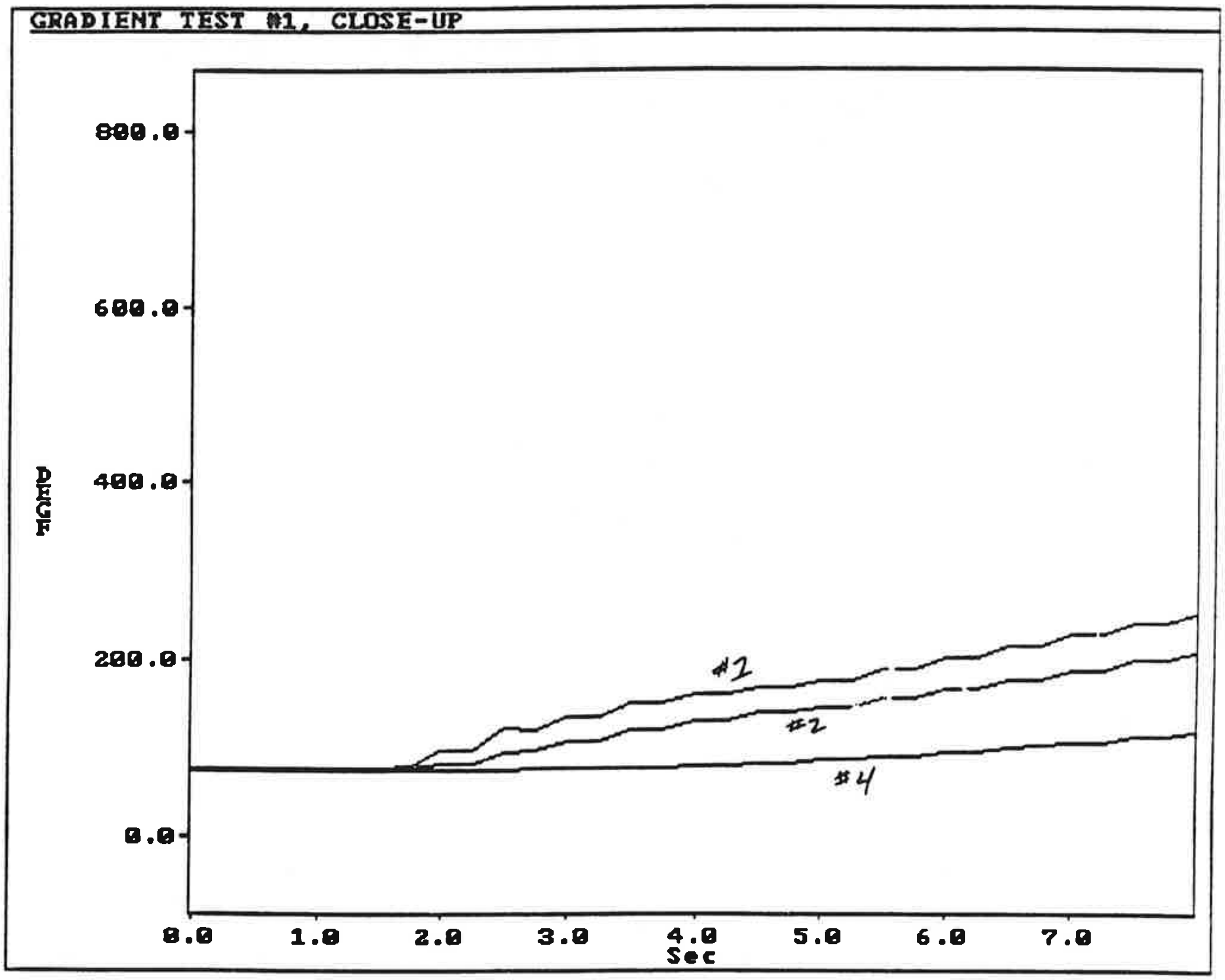
Graphs 2 and 3 reveal the results of the thermal gradient test. Again the actual results mimicked the anticipated results. The response resolution between each thermocouple in the thermo-plug is clearly discernible under the test conditions and, therefore, should be discernible under the actual test conditions. The survivability test in this part of the procedure consisted of verifying electrical continuity of the thermocouples after they experienced the thermal shock in the gradient test. All thermocouples passed this examination.



Graph 2 Thermal Gradient Overall

6.3 ELECTRICAL ISOLATION TEST

The thermocouples were tested, after undergoing thermal shock-loading, for electrical isolation between each other and from the thermo-plug steel. All thermo-plugs passed the requirements described in the test plan.



Graph 3 Thermal Gradient Close-Up

6.4 POST-INSTALLATION CHECK

After installation in the test wheels and hand-contouring to match the tread profile, the thermo-plugs were exercised, using a propane torch, to verify their response. Data was recorded by the data acquisition system and graphed to illustrate the results. All thermo-plug data curves closely resembled the general shape of the curves generated in the thermal gradient test procedure. Therefore, no damage was done to the assemblies and the instrumentation was declared ready for installation on the test consist for the start of the test procedure.

6.5 THERMOCOUPLE POSITION IN WHEEL

After passing the post-installation check, the thermo-plugs were measured to determine the depth-within-tread of the thermocouples using the measurement jig. The jig performed well, producing repeatable depth readings, and was used throughout the installation and test procedures.

APPENDIX II

THERMOCOUPLE
DATA
PRESENTATION

TABLE of CONTENTS

10210024	L2	6	Same as above	20
10210024	L2	7	Same as above	21
10210053	L1	4	Location: County to Fair Speed up to 95 mph - Full service stop - 680 deg. F maximum seen	22
10210053	L2	6	Same as above	23
10210053	L2	7	Same as above	24
10210107	L1	4	Location: County to Fair Started to rain Speed up to 95 mph - Full service stop - 802 deg. F maximum seen	25
10210107	L2	6	Same as above	26
10210107	L2	7	Same as above	27
10210136	L1	4	Location: Fair to Highstown Speed up to 97 mph - Slow down to 70 mph - Full service braking - 680 deg. F maximum seen Speed up to 96 mph - Slow down to 70 mph - Full service braking - 680 deg. F maximum seen Speed up to 91 mph - Full service stop - 800 deg. F maximum seen	28
10210136	L2	6	Same as above	29
10210136	L2	7	Same as above	30
10210202	L1	4	Location: Highstown to County Interlock Speed up to 93 mph - Slow down to 70 mph - 20 lbf reduction - 450 deg. F maximum seen Speed up to 87 mph - Slow down to 30 mph - 833 deg. F maximum seen	31
10210202	L2	6	Same as above	32
10210202	L2	7	Same as above	33

10210215	L1	4	Location: County Interlock to Fair Speed up to 98 mph - Slow down to 70 mph - 15 lbf reduction - 501 deg. F maximum seen Speed up to 95 mph - Slow down to 70 mph - 10 lbf reduction Speed up to 94 mph - Slow down to 0 mph - Full service braking - 851 deg. F maximum seen	34
10210215	L2	6	Same as above	35
10210215	L2	7	Same as above	36
10210234	L1	4	Location: County Interlock to Fair Speed up to 90 mph - Full service stop - 885 deg. F maximum seen	37
10210234	L2	6	Same as above	38
10210234	L2	7	Same as above	39
10210256	L1	4	Location: Fair to County Speed up to 94 mph - Slow down to 0 mph - 20 lbf reduction - 860 deg. F maximum seen	40
10210256	L2	6	Same as above	41
10210256	L2	7	Same as above	42
10210303	L1	4	Location: Fair to County Speed up to 90 mph - Slow down to 0 mph - 10 lbf reduction - 989 deg. F maximum seen Stopped for five seconds Speed up to 91 mph - Slow down to 0 mph - 10 lbf reduction - 872 deg. F maximum seen	43
10210303	L2	6	Same as above	44
02103031	L2	7	Same as above	45

10210314	L1	4	Location: Fair to County Speed up to 83 mph - Slow down to 55 mph - 695 deg. F maximum seen Speed up to 82 mph - Slow down to 60 mph - 802 deg. F maximum seen Speed up to 83 mph - Slow down to 55 mph - 894 deg. F maximum seen Speed up to 77 mph - Slow down to 33 mph - 922 deg. F maximum seen	46
10210314	L2	6	Same as above	47
10210314	L2	7	Same as above	48
10210335	L1	4	Location: Union to Matawan Station Speed up to 95 mph - Full service reduction to 45 mph Bearing failure in L2 slip ring housing 0.5" crack found on tread surface of L2 in two different places	49
10210335	L2	6	Same as above	50
10210335	L2	7	Same as above	51
10220003	L1	4	Location: County to Princeton Junction on Track 3 Speed up to 100 mph - Full service stop - 816 deg. F maximum seen Thermo-picture taken on wheel	52
10220003	L2	6	Same as above	53
10220003	L2	7	Same as above	54
10220039	L1	4	Location: Princeton Junction to Fair Speed up to 99 mph - Slow down to 41 mph - 805 deg. F maximum seen	55
10220039	L2	6	Same as above	56
10220039	L2	7	Same as above	57

10220057	L1	4	Location: Fair to Princeton Junction Speed up to 100 mph - Full service brake reduction - 898 deg. F maximum seen	58
10220057	L2	6	Same as above	59
10220057	L2	7	Same as above	60
10220118	L1	4	Location: Princeton Junction to County Speed up to 98 mph - Slow down to 37 mph - Full service reduction applied then stop - 890 deg. F maximum seen	61
10220118	L2	6	Same as above	62
10220118	L2	7	Same as above	63
10220142	L1	4	Location: County to Princeton Junction New brakes shoes installed Speed up to 100 mph - Full service stop - 604 deg. F maximum seen	64
10220142	L2	6	Same as above	65
10220142	L2	7	Same as above	66
10220201	L1	4	Location: Fair to Princeton Speed up to 100 mph - Full service brakes (65 psi) - 575 deg. F maximum seen	67
10220201	L2	6	Same as above	68
10220201	L2	7	Same as above	69
10220239	L1	4	Location: Princeton to Princeton Junction on Track 3 Speed up to 100 mph - Full service stop - 632 deg. F maximum seen	70
10220239	L2	6	Same as above	71
10220239	L2	7	Same as above	72
10220256	L1	4	Location: Princeton Junction to County Speed up to 100 mph - 10 lbf reduction	73
10220256	L2	6	Same as above	74
10 220256	L2	7	Same as above	75

10220304	L1	4	Location: County to Princeton Speed up to 100 mph - Then emergency stop - 703 deg. F maximum seen	76
10220304	L2	6	Same as above	77
10220304	L2	7	Same as above	78
10220316	L1	4	Location: Princeton to Fair on Track 3 Speed up to 100 mph - Full service stop - 702 deg. F maximum seen	79
10220316	L2	6	Same as above	80
10220316	L2	7	Same as above	81

NJT Wheel Temperature Data:

Maximum Temperature Gradient Analysis

File	Wheel # L1 Pos # 3			Wheel # L1 Pos # 4			Wheel # L2 Pos# 6			Wheel # L2 Pos# 7		
	0.1" Max	0.5" Value**	Difference	0.1" Max	0.5" Value**	Difference	0.1" Max	0.5" Value**	Difference	0.1" Max	0.5" Value**	Difference
10192128	475	211	264	463	208	255	346	171	175	325	189	136
10192137	568	358	210	582	363	219	675	357	318	491	368	123
10192159	664	450	214	668	458	210	559	354	205	458	388	70
10202318*	252	152	100	287	164	123	117	87	30	91	82	9
10202337*	181	99	82	153	100	53	119	90	29	98	93	5
10202358*	176	133	43	137	117	20	179	117	62	112	104	8
10210024	677	499	178	693	466	227	821	500	321	656	502	154
10210053	N/A***	N/A	N/A	646	467	179	688	502	186	588	467	121
10210107	N/A	N/A	N/A	688	461	227	802	583	219	750	562	188
10210136	N/A	N/A	N/A	686	404	282	809	576	233	728	559	169
10210202	N/A	N/A	N/A	640	522	118	837	635	202	736	594	142
10210215	N/A	N/A	N/A	693	559	134	853	624	229	732	579	153
10210234	N/A	N/A	N/A	710	581	129	886	666	220	790	633	157
10210256	N/A	N/A	N/A	637	518	119	860	607	253	744	593	151
10210303	N/A	N/A	N/A	672	556	116	991	651	340	795	641	154
10210314	N/A	N/A	N/A	748	567	181	937	699	238	788	652	136
10210335	N/A	N/A	N/A	725	532	193	805	618	187	750	600	150
10220003	N/A	N/A	N/A	667	498	169	816	581	235	736	533	203
10220039	N/A	N/A	N/A	645	494	151	813	575	238	764	553	211
10220057	N/A	N/A	N/A	692	522	170	900	631	269	743	561	182
10220118	N/A	N/A	N/A	731	566	165	897	670	227	897	645	252
10220142	N/A	N/A	N/A	604	490	114	587	474	113	579	467	112
10220201	N/A	N/A	N/A	585	484	101	635	505	130	590	494	96
10220239	N/A	N/A	N/A	589	483	106	637	483	154	583	482	101
10220256	N/A	N/A	N/A	490	411	79	578	447	131	546	450	96
10220304	N/A	N/A	N/A	610	501	109	706	570	136	667	556	111
10220316	N/A	N/A	N/A	628	525	103	706	501	205	618	534	84
Averages	569.00	339.67	229.33	645.50	484.83	160.67	756.00	540.83	215.17	668.92	525.08	143.83

* SYSTEM CALIBRATION FILES, NOT INCLUDED IN AVERAGES
** 0.5" VALUES WHEN 0.1" VALUE REACHES MAXIMUM
*** INSTRUMENTATION FAILURE, NO DATA RECORDED

Car Inspection Data

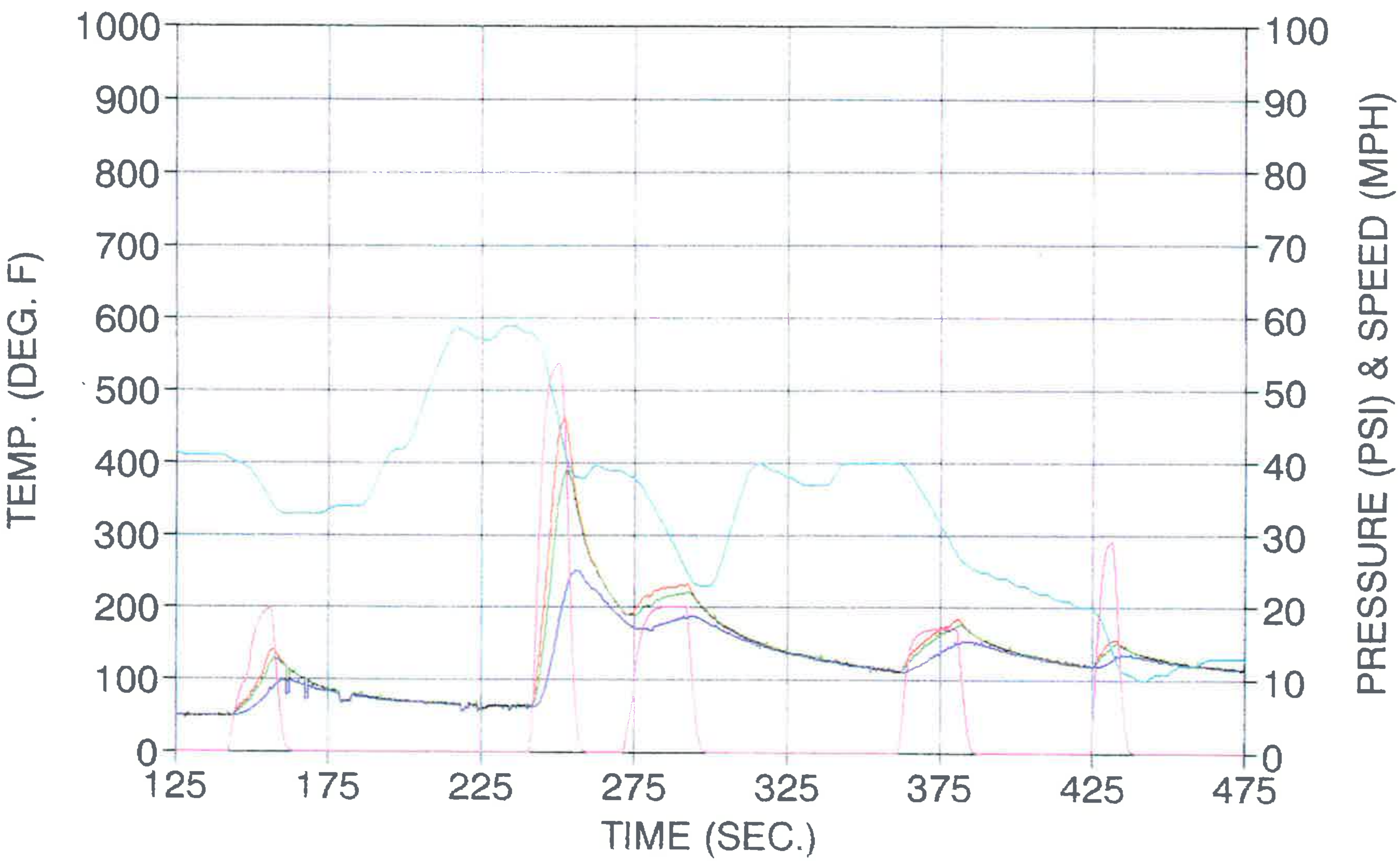
POSITION	TREAD	RIM	PLATE	BRAKE SHOE	REMARKS
L1	OK	2.5 Disc to RPF	(S) OK	2 cracks	
L2	TC indic 1/4" toward ctr tread but toward edge	2.5	(S) OK	2 cracks	
L3	OK	2	Disc to 3.5" ctr tread toward rim edge 1/8"	4 cracks (worn)	By tape rim 1 7/8"
L4	Heat checks & some TC ctr tread	2	Disc to 3 in (S)	2 cracks	Wipe revealed mech cracks & a few thermal cracks ctr read ~ 3/4 to 1"
L5	ISDC mech 1/4"	2.5	(S)	1 crack	
L6	Minor surface checks 1/16" 0 x < 005" deep	2.5	(S)	2 cracks	
L7	OK	1.75		new	
L8	OK	1.75 Disc to RPF		new	
L9	OK	2.5 Disc to RPF	(S)	1 crack	
L10	OK	2.5 Disc to RPF	(S)		
L11	OK	1+	Disc to 4 in	1 crack	CTR #3 TC
L12	OK	1+		1 crack	
L13	OK	1+ Blued Edge	Disc to 3 in	1 crack	Both shoes riding inward of ctr - not on edge
L14	OK	1+ Very Blued Edge	Disc to 3.5 in	2 cracks	Both shoes riding inward of ctr - not on edge
L15	OK	2.5	(S)	1 crack	
L16	OK	2 625	(S)	1 crack	
R16	OK	2 625	(S)	new	
R15	OK	2.5	(S)	1 crack	
R14	OK	1+	Disc to 3.5 in	2 cracks	
R13	OK	1+	Disc to 3.5 in	1 crack	
R12	OK	1+	Disc to 4 in	OK	"1412 #1 TC"
R11	OK	1+	Disc to 4 in	1 crack	
R10	OK?	2.5	(S)	1 crack	View of tread obstructed by electrical box
R9	OK	2.5	(S)	1 crack	
R8	OK	2	Disc to 4.5 in	2 cracks	
R7	Minor indents like L6	2	Disc to 4.5 in	2 cracks	
R6	OK	2.5 Disc to RPF	(S)	2.5 cracks	But shoe is new
R5	Minor indents like L6 & R7	2.5 Disc to RPF	(S)	2 cracks	
R4	OK	2" Disc to RPF	(S)	OK	
R3	Indicate Ctr tread 1/8"	1.5"	Disc to 4.5 in	1.5 cracks	
R2	OK	2.5 LITE Disc to RPF	(S)	2 cracks	
R1	Minor indents like L6, R7 & R5	2.5"	(S)	2 cracks	

RPF Rim/Plate Fillet
TC – Thermal Cracks
Disc – Black Discolor
RPF – Rim/Plate Fillet
S' Plate Whole (S)
CTR – Center

Note Remspect L3 with flashlight
Still hard to see everything because of rust band
Tried emery & paper towel & paper towel only (best result)
→ revealed 1/2" CTR tread mech cracks & Z sld flats
~ 3/4" long ~@ 90 degrees

NJT WHEEL TEMPERATURE DATA

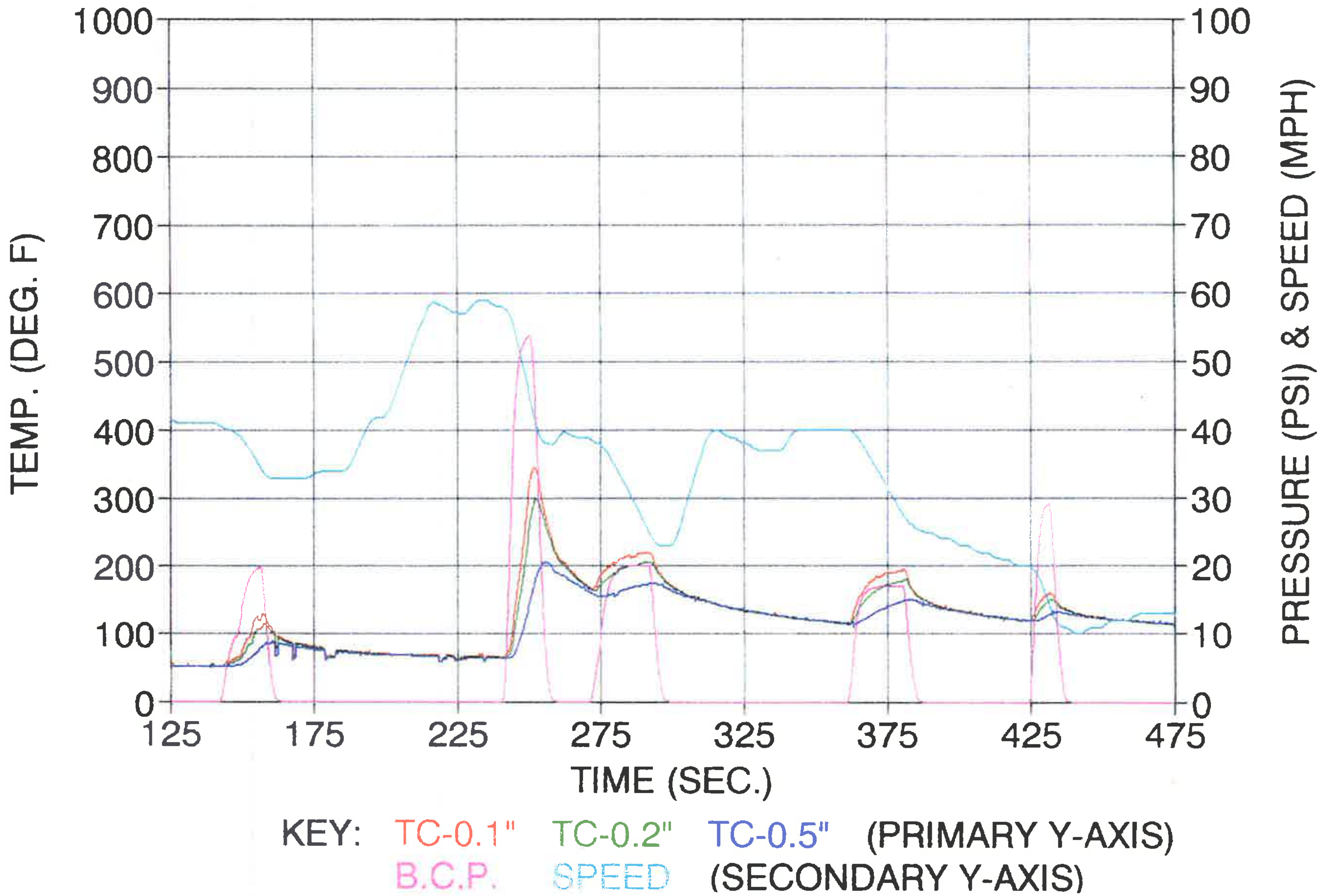
FILE:10192128 WHEEL#:L1 POS.#:4

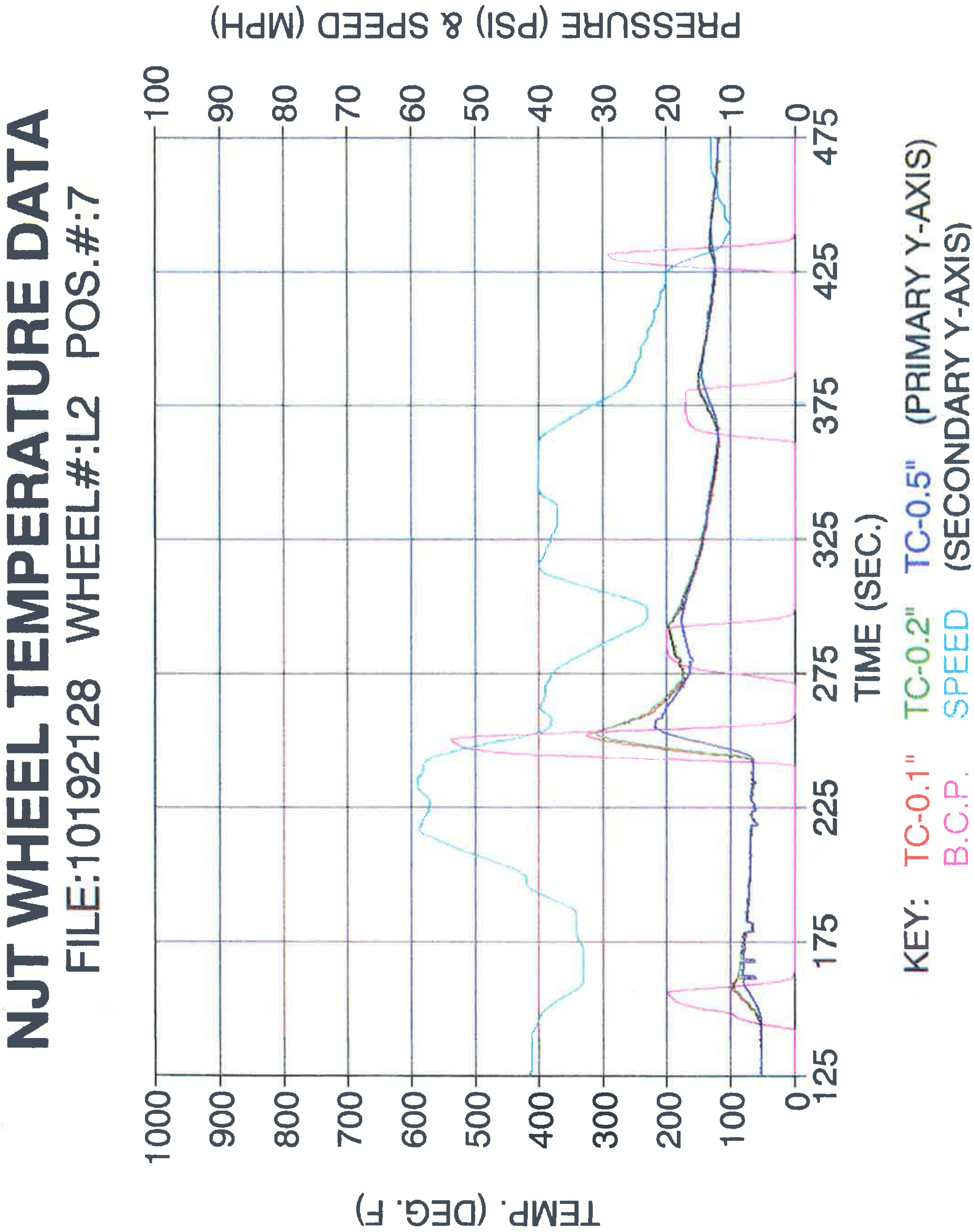


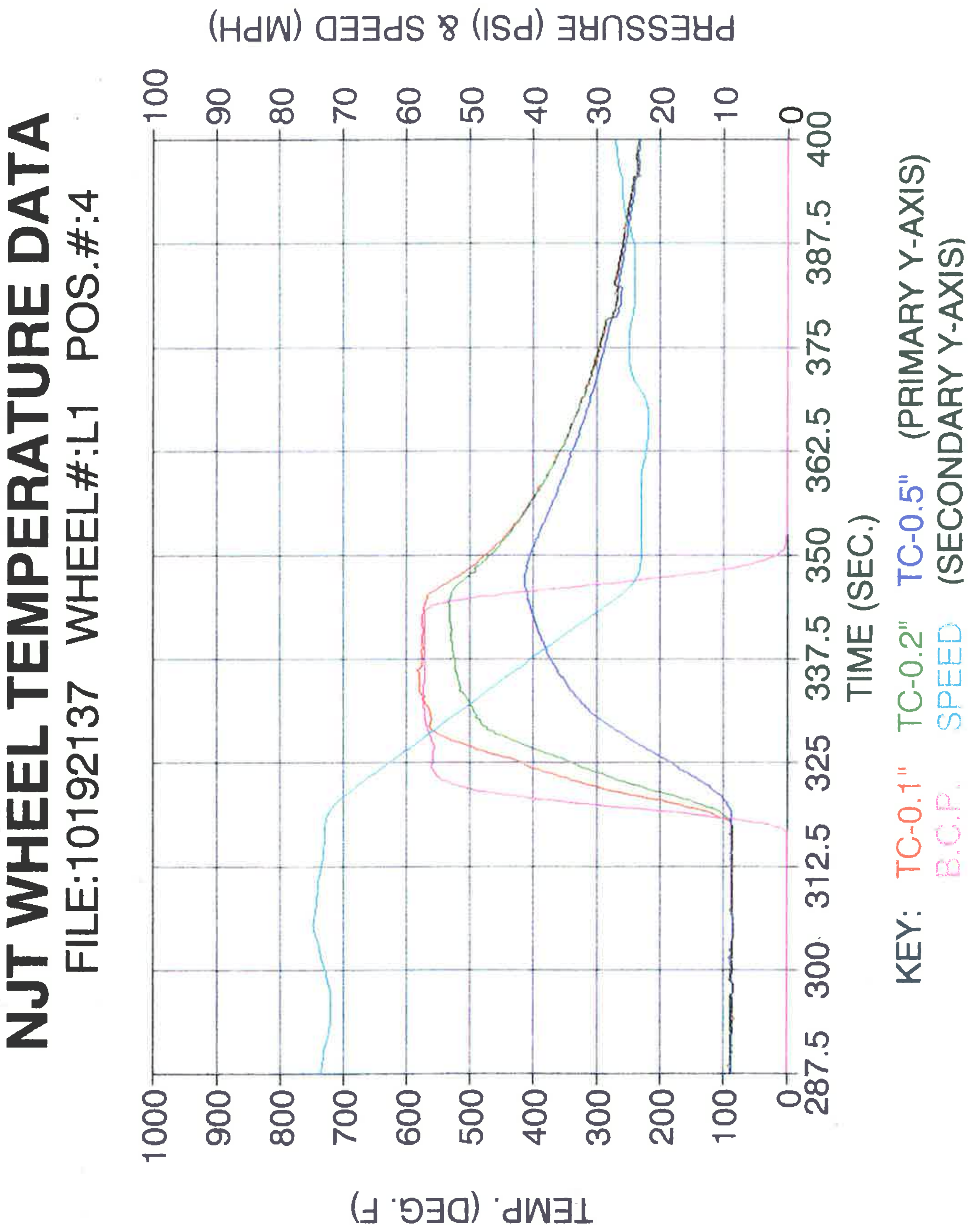
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

FILE:10192128 WHEEL#:L2 POS.#:6

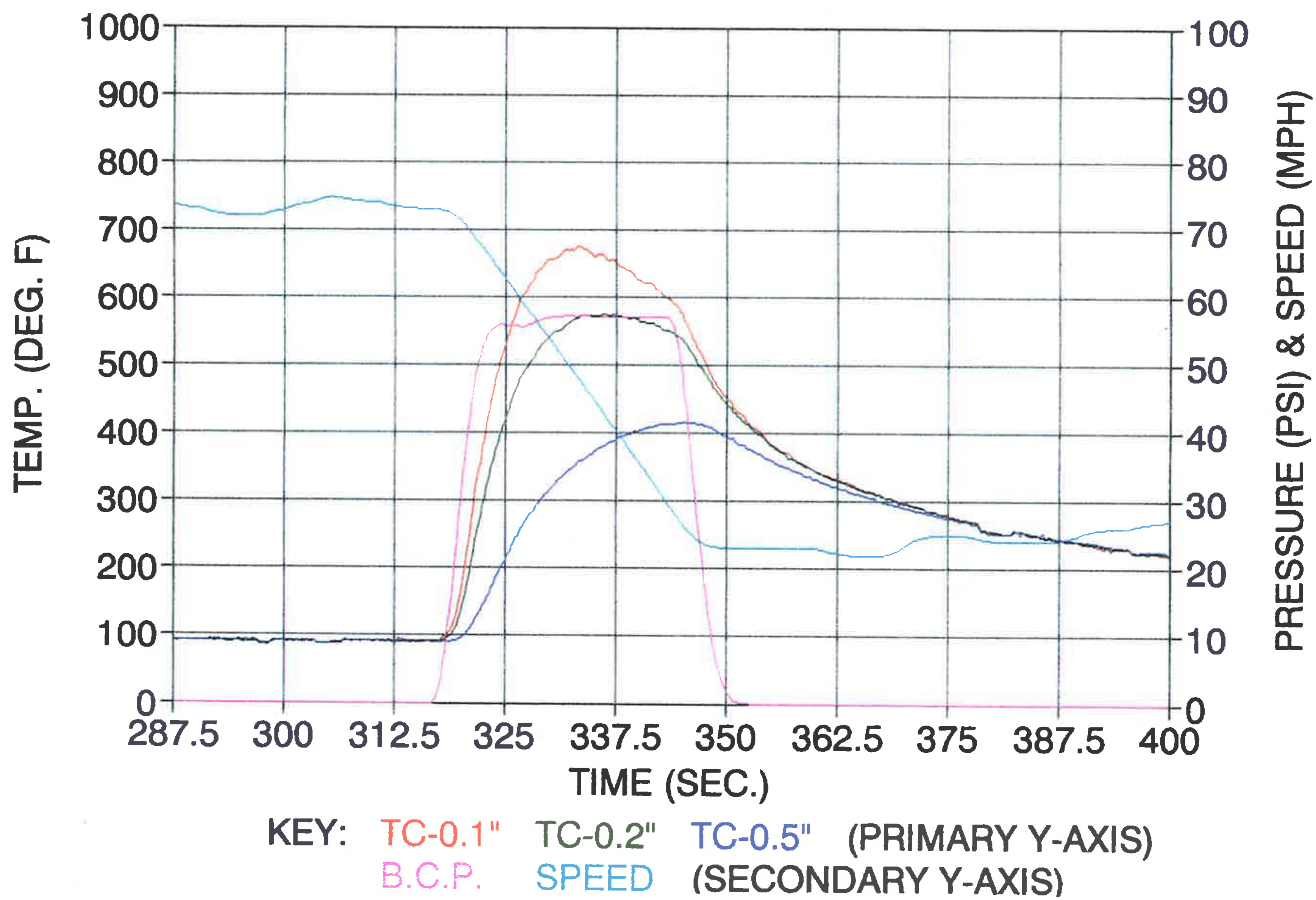



NJT WHEEL TEMPERATURE DATA
FILE:10192128 WHEEL#:L2 POS.#:7
TEMP. (DEG. F)
PRESSURE (PSI) & SPEED (MPH)
TIME (SEC.)
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)


NJT WHEEL TEMPERATURE DATA
FILE:10192137 WHEEL#:L1 POS.#:4
TEMP. (DEG. F)
PRESSURE (PSI) & SPEED (MPH)
TIME (SEC.)
0
100
200
300
400
500
600
700
800
900
1000
10
20
30
40
50
60
70
80
90
287.5
300
312.5
325
337.5
350
362.5
375
387.5
400
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

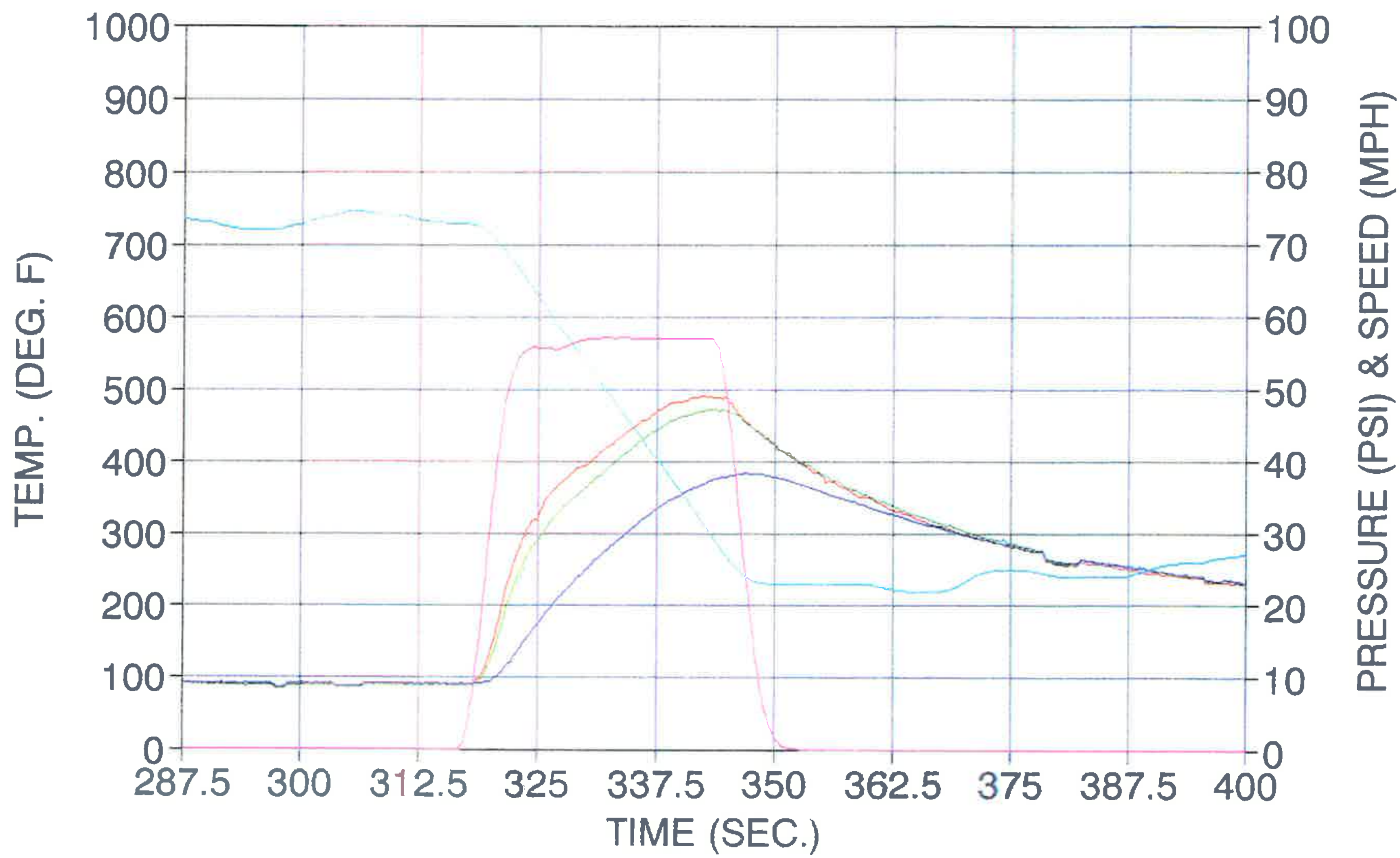
NJT WHEEL TEMPERATURE DATA

FILE:10192137 WHEEL#:L2 POS.#:6



NJT WHEEL TEMPERATURE DATA

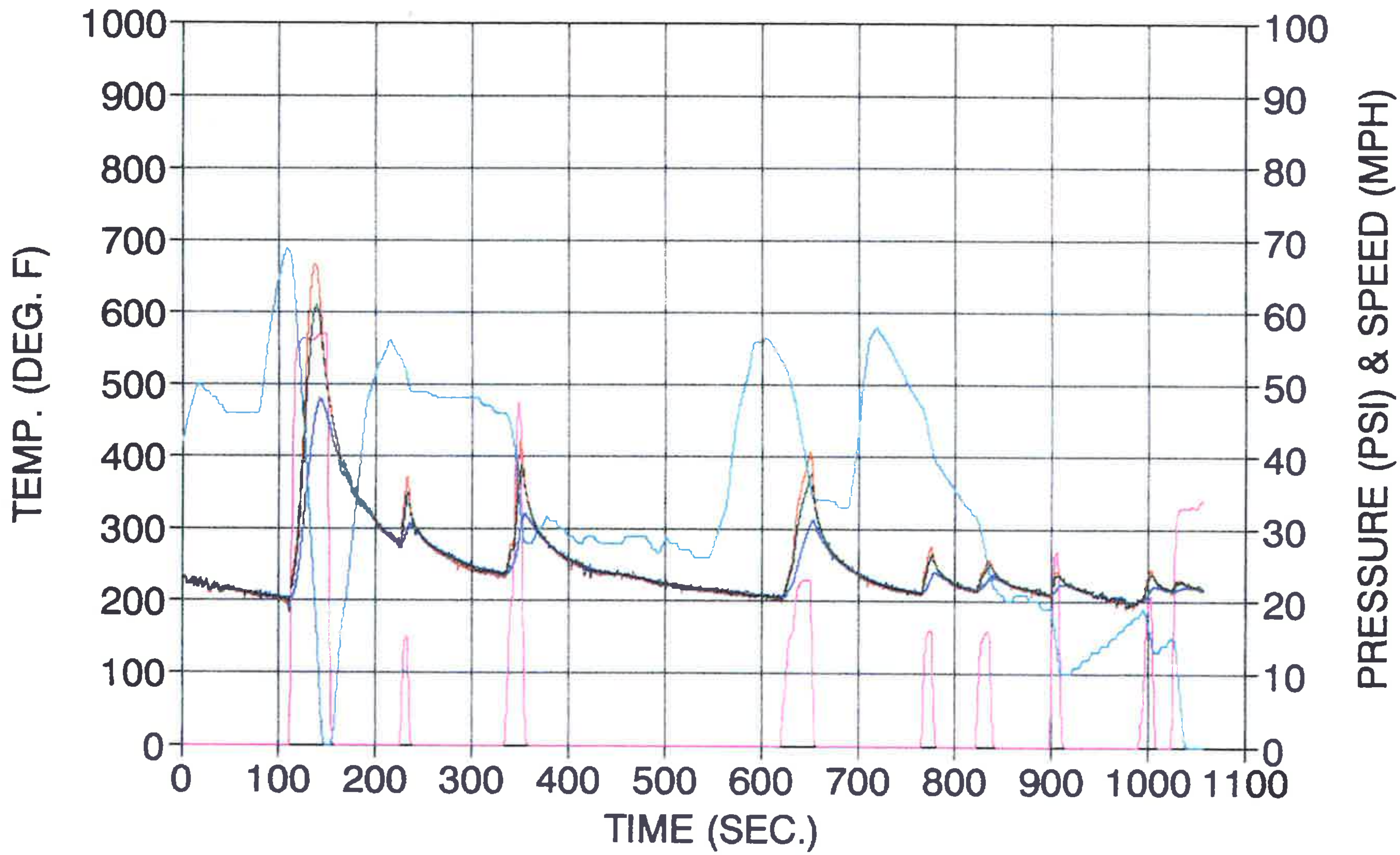
FILE:10192137 WHEEL#:L2 POS.#:7



KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

FILE:10192159 WHEEL#:L1 POS.#:4

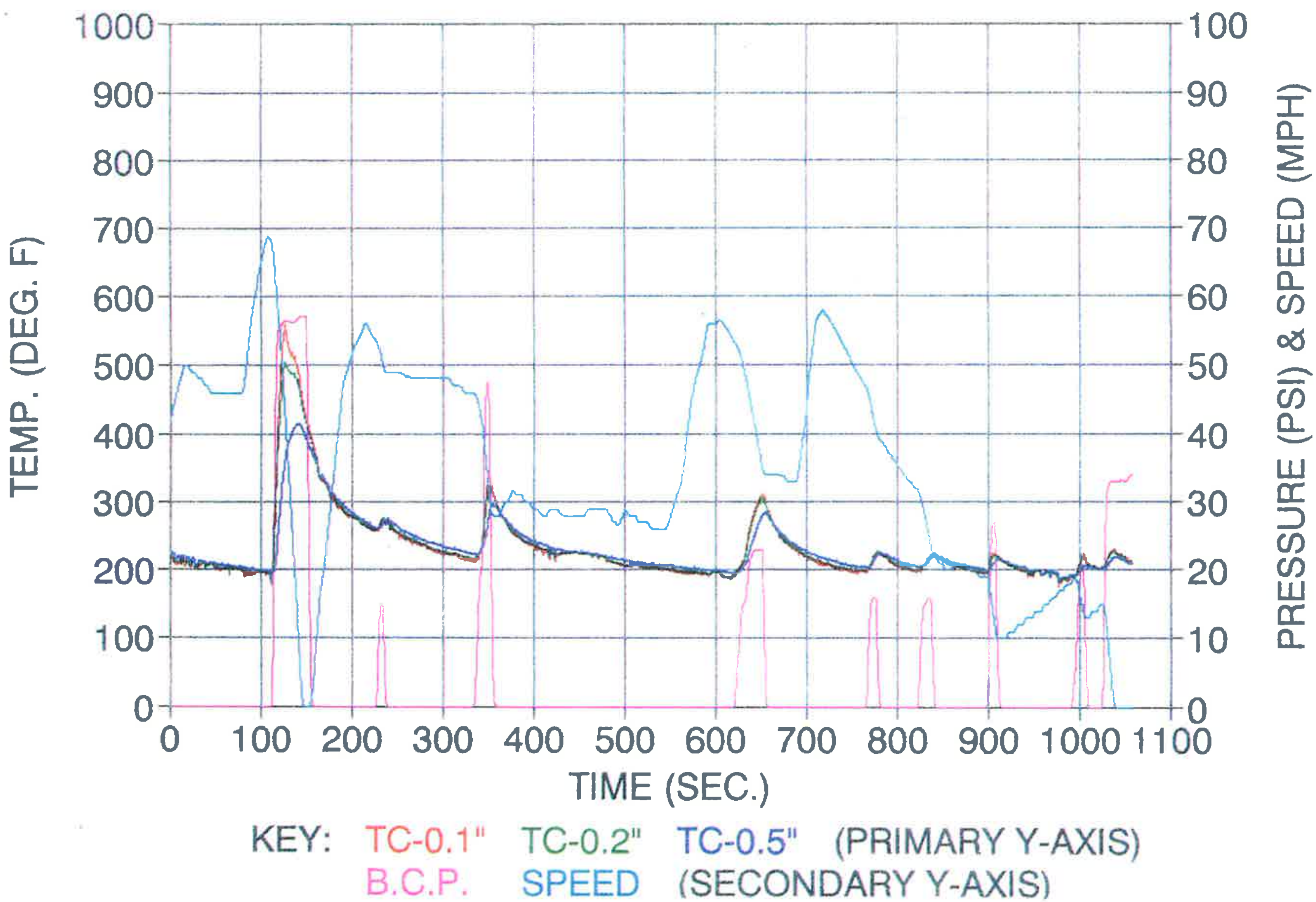


KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)

B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

FILE:10192159 WHEEL#:L2 POS.#:6



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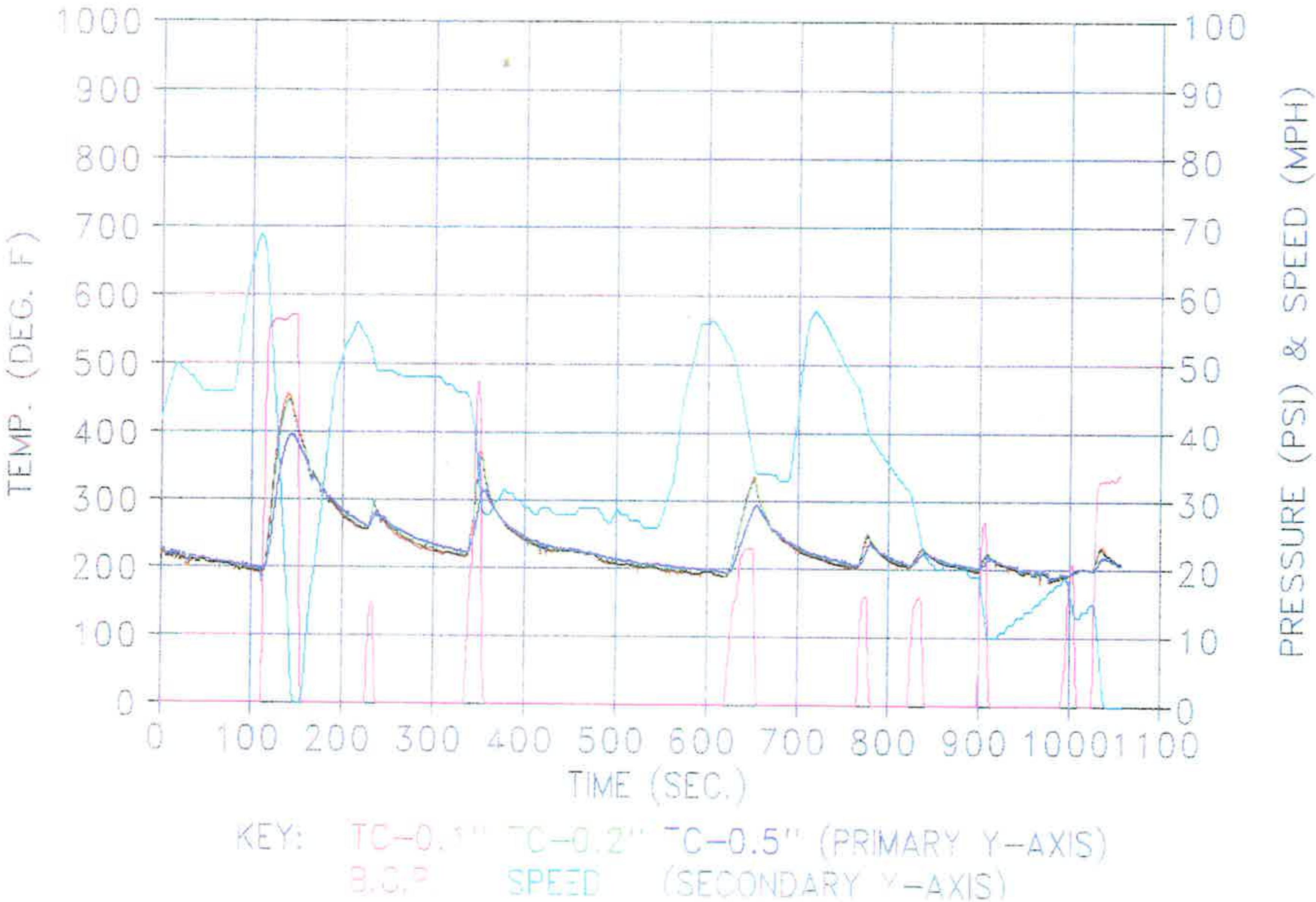
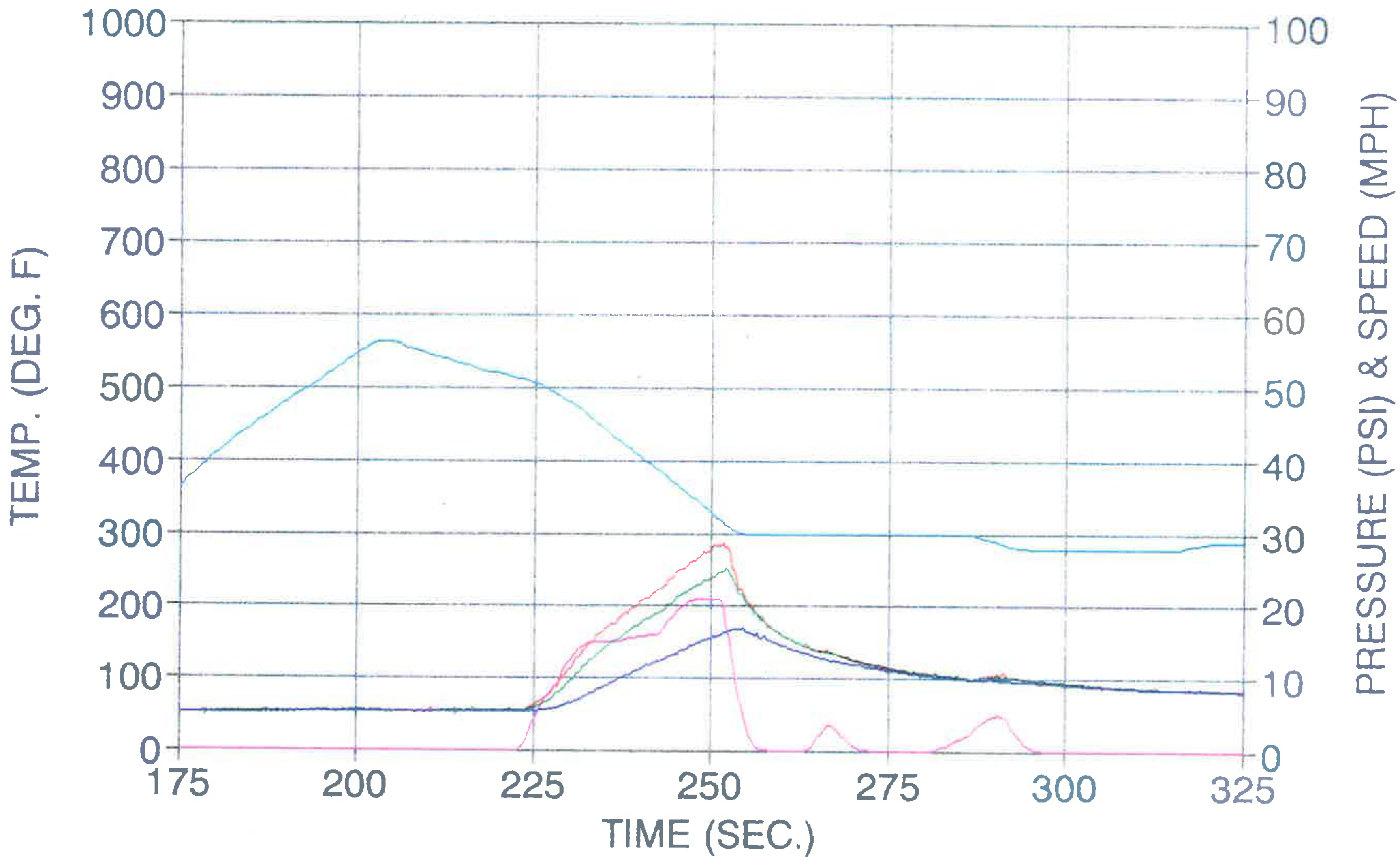
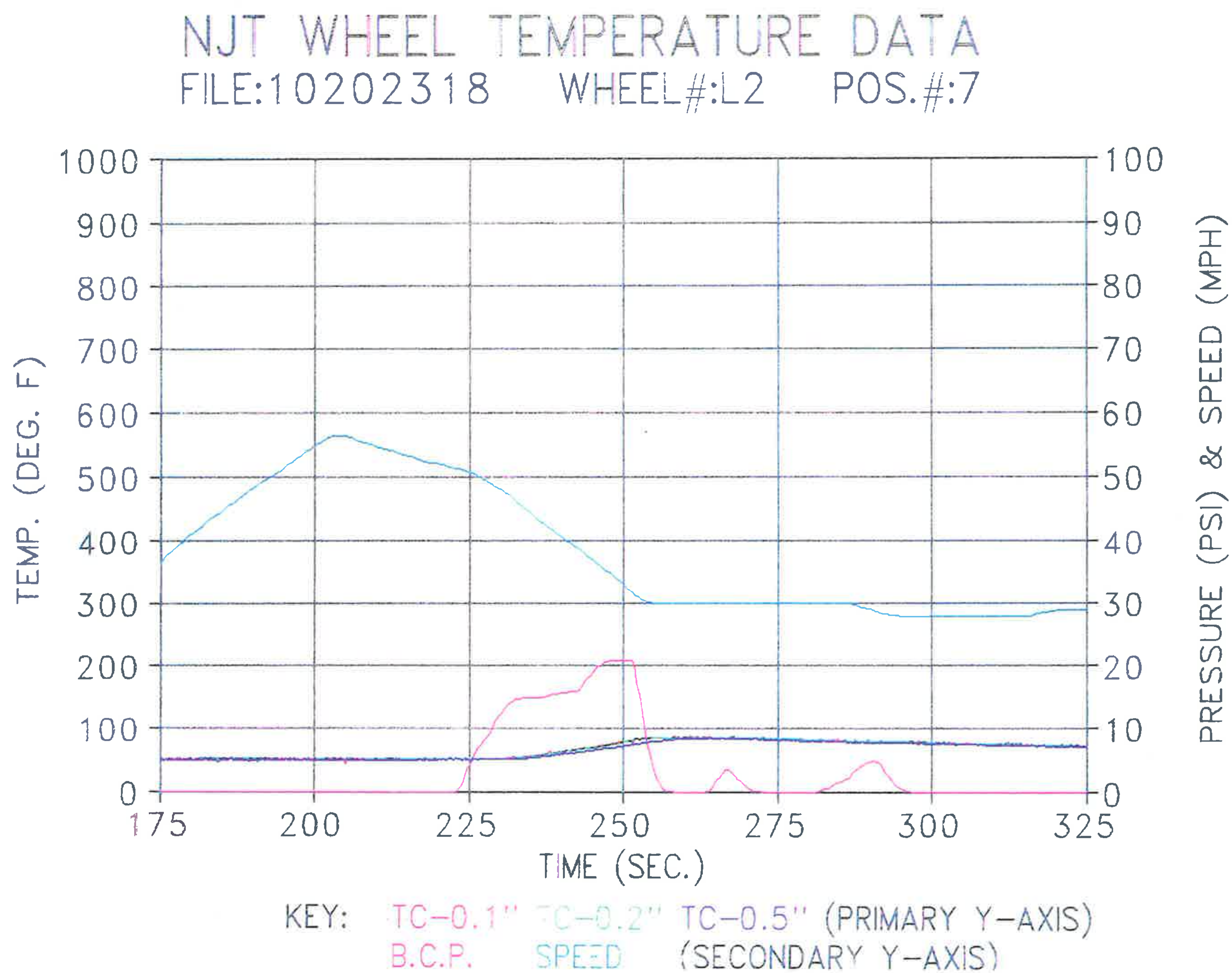


NJT WHEEL TEMPERATURE DATA

FILE:10202318 WHEEL#:L1 POS.#:4

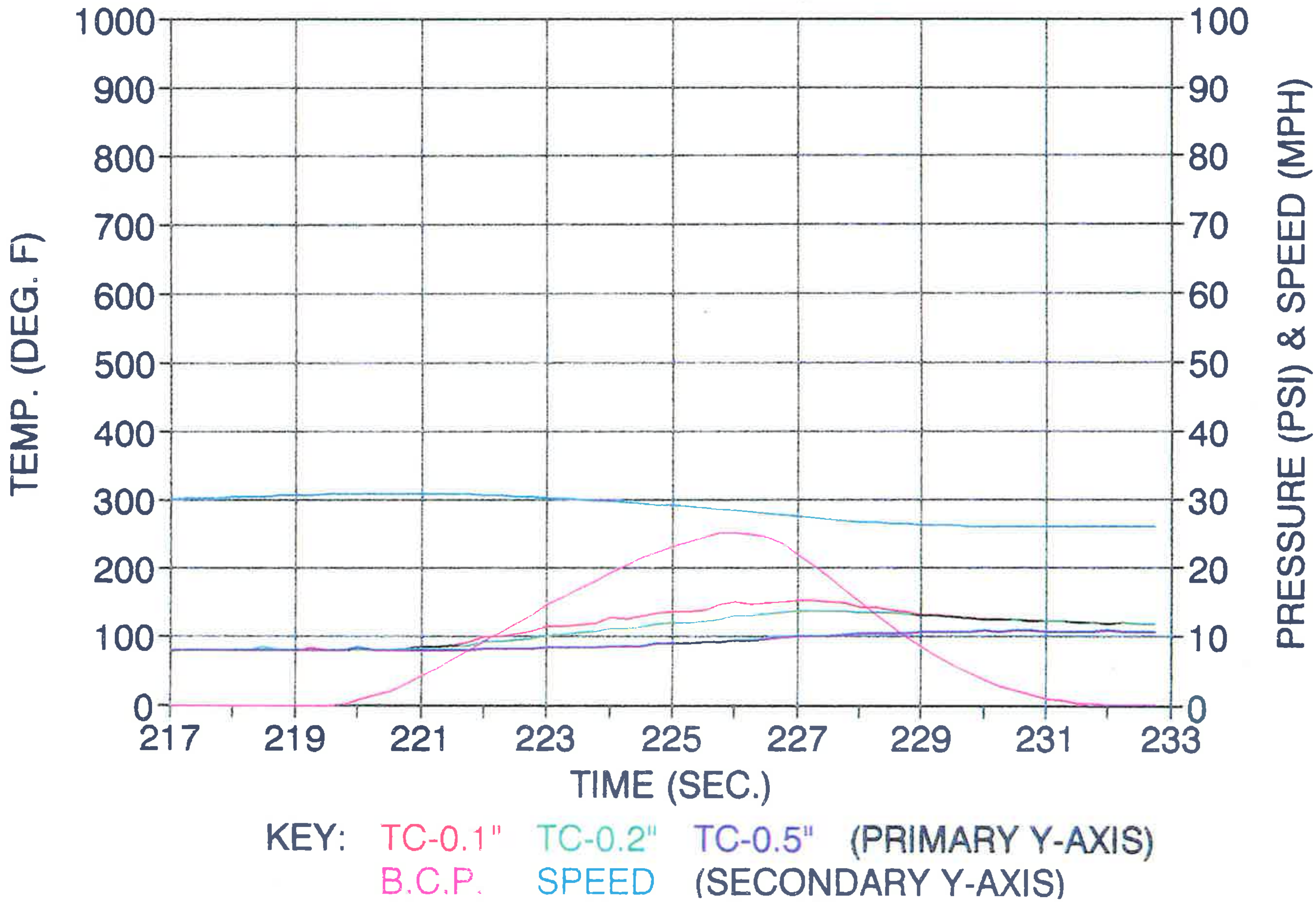


KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)


NJT WHEEL TEMPERATURE DATA
FILE:10202318 WHEEL#:L2 POS.#:7
TEMP. (DEG. F)
1000
900
800
700
600
500
400
300
200
100
0
PRESSURE (PSI) & SPEED (MPH)
100
90
80
70
60
50
40
30
20
10
0
175
200
225
250
275
300
325
TIME (SEC.)
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

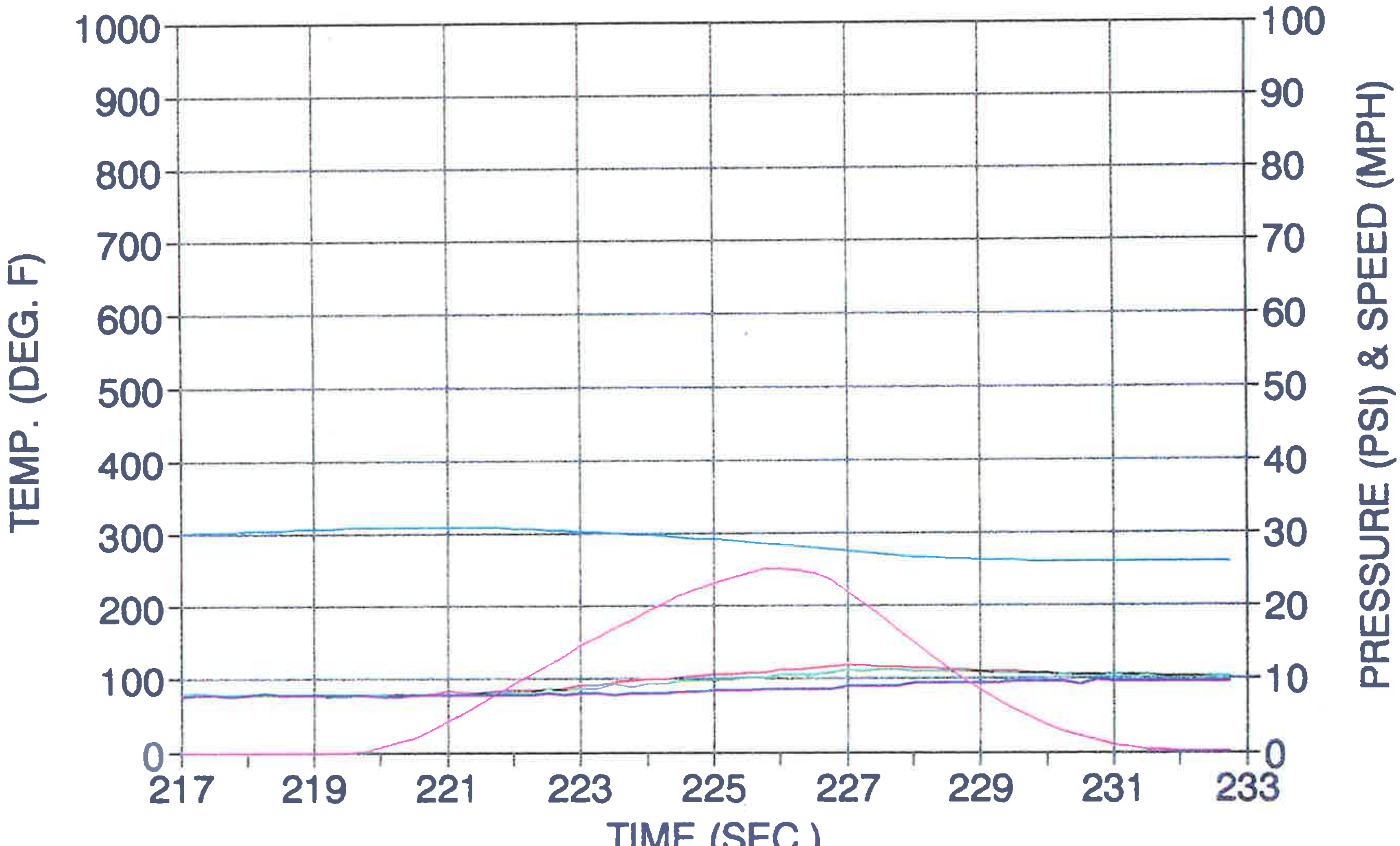
NJT WHEEL TEMPERATURE DATA

FILE:10202337 WHEEL#:L1 POS.#:4

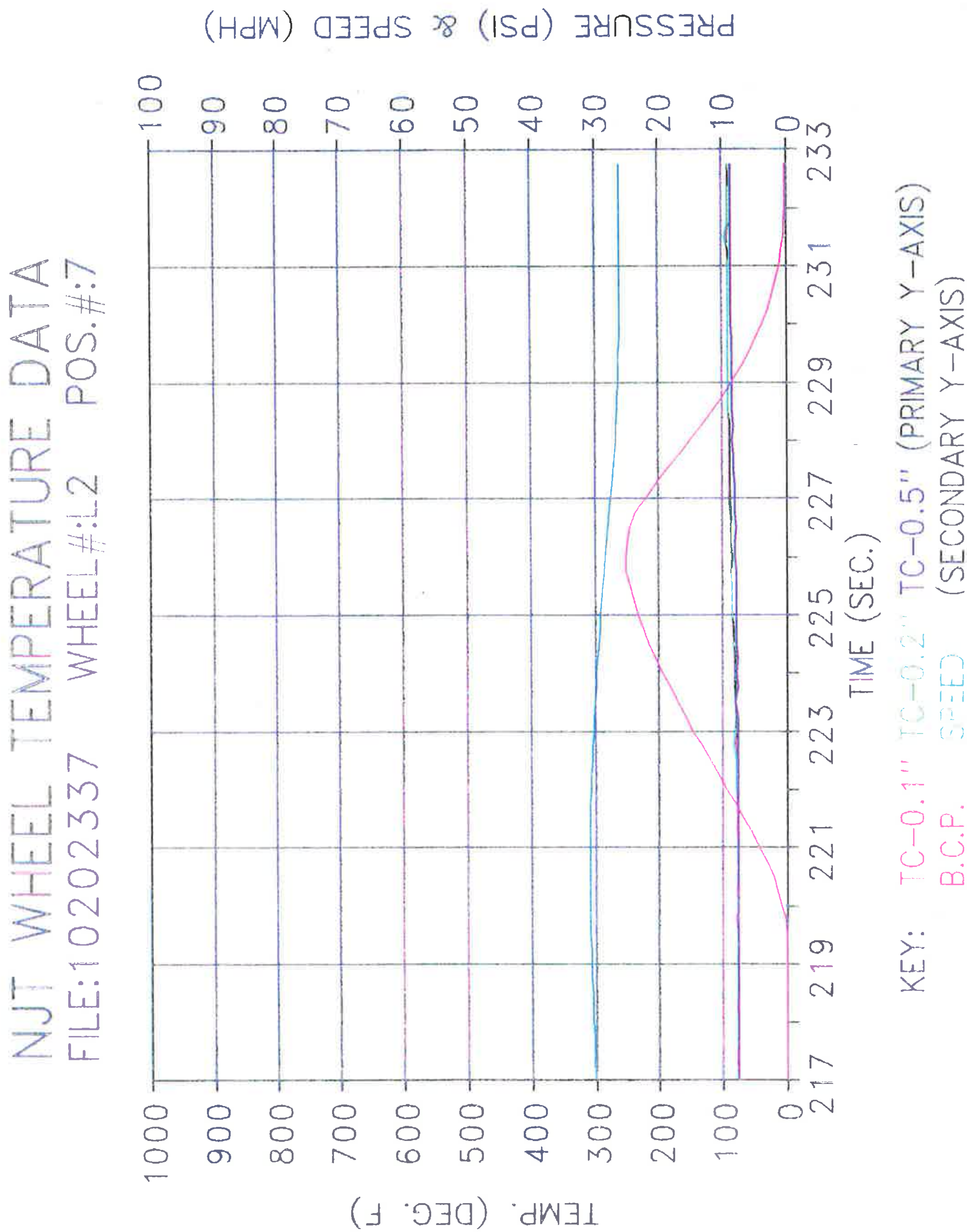


NJT WHEEL TEMPERATURE DATA

FILE:10202337 WHEEL#:L2 POS.#:6

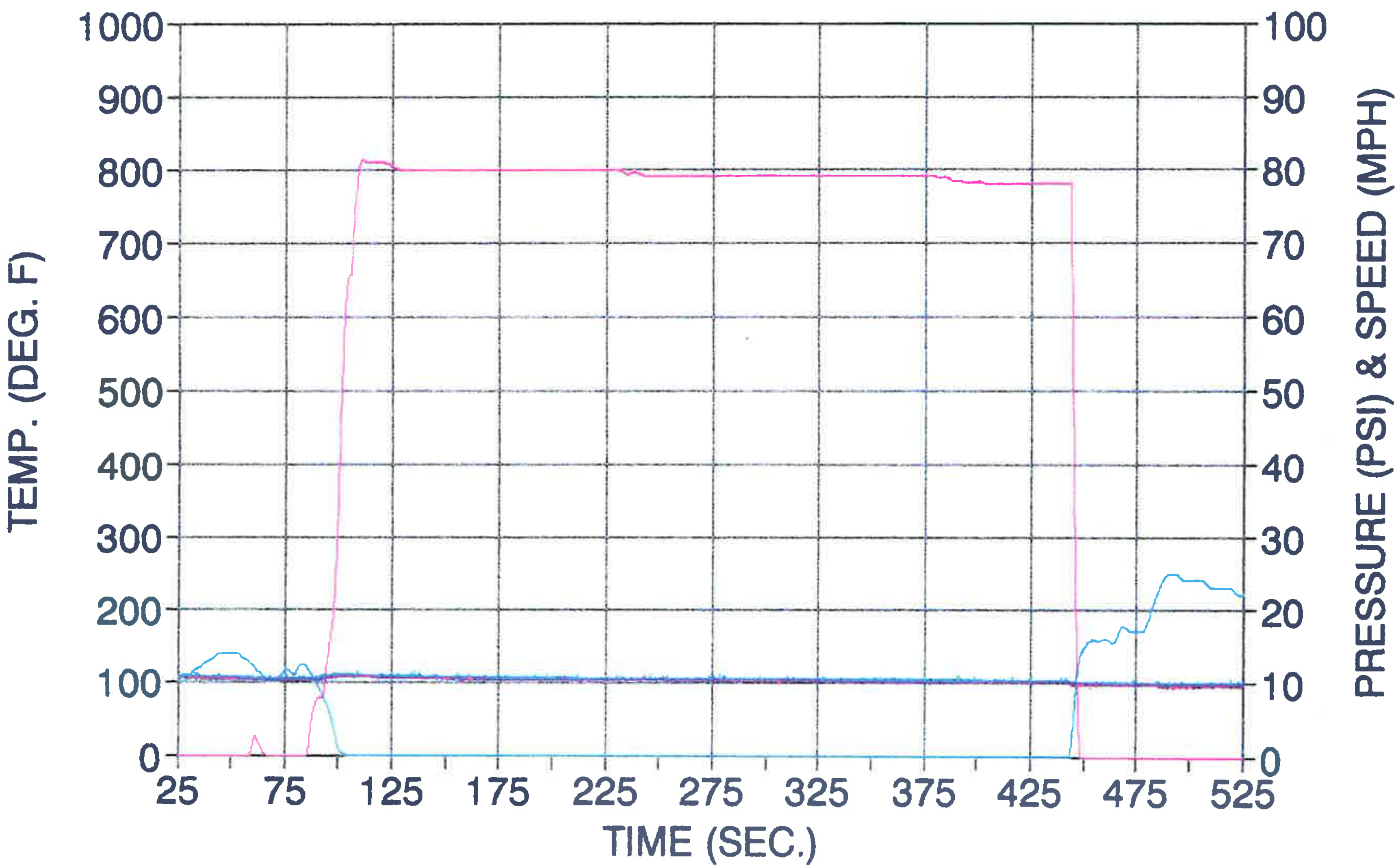


KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

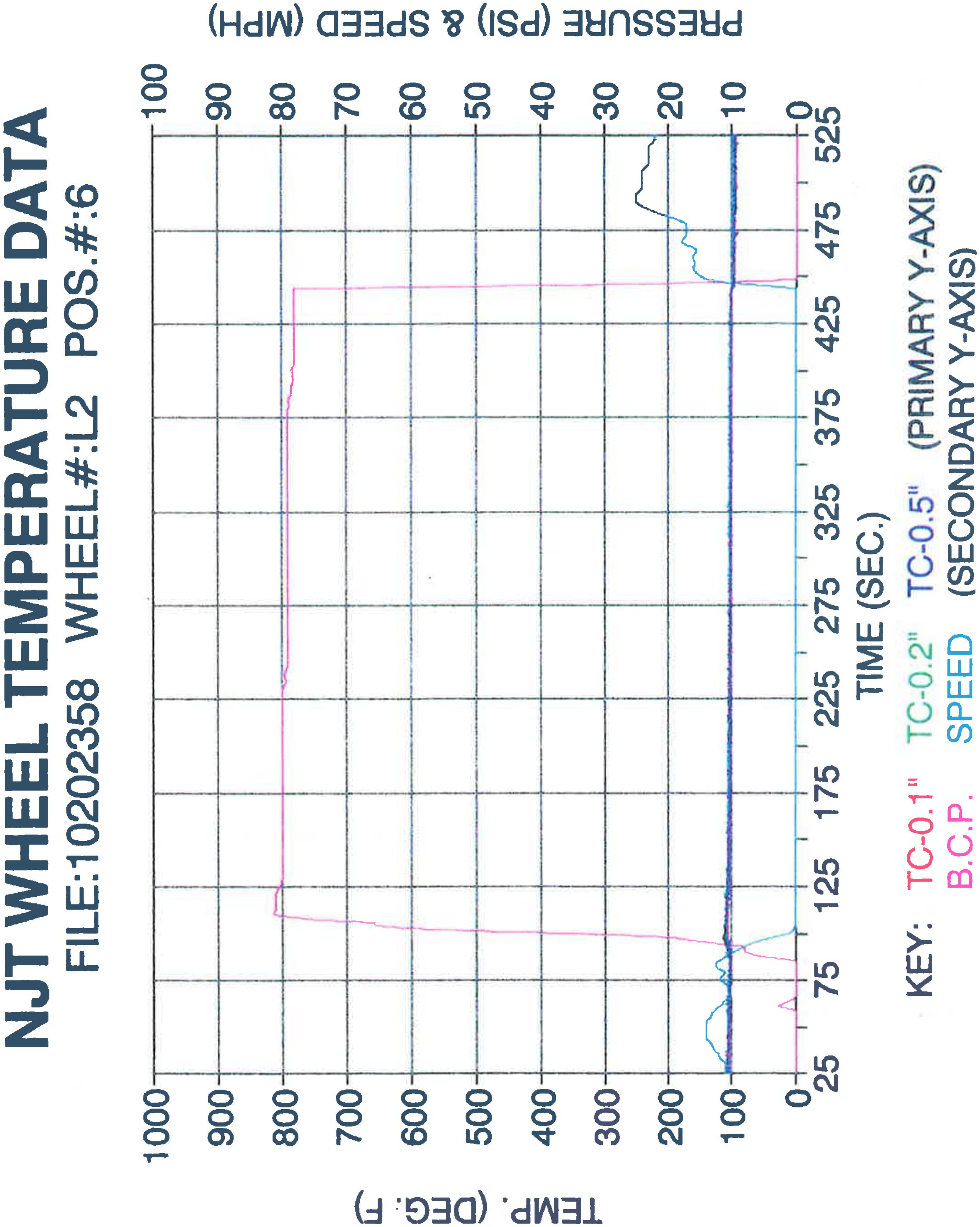

NJT WHEEL TEMPERATURE DATA
FILE:10202337 WHEEL#:L2 POS.#:7
PRESSURE (PSI) & SPEED (MPH)
TEMP. (DEG. F)
TIME (SEC.)
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

FILE:10202358 WHEEL#:L1 POS.#:4

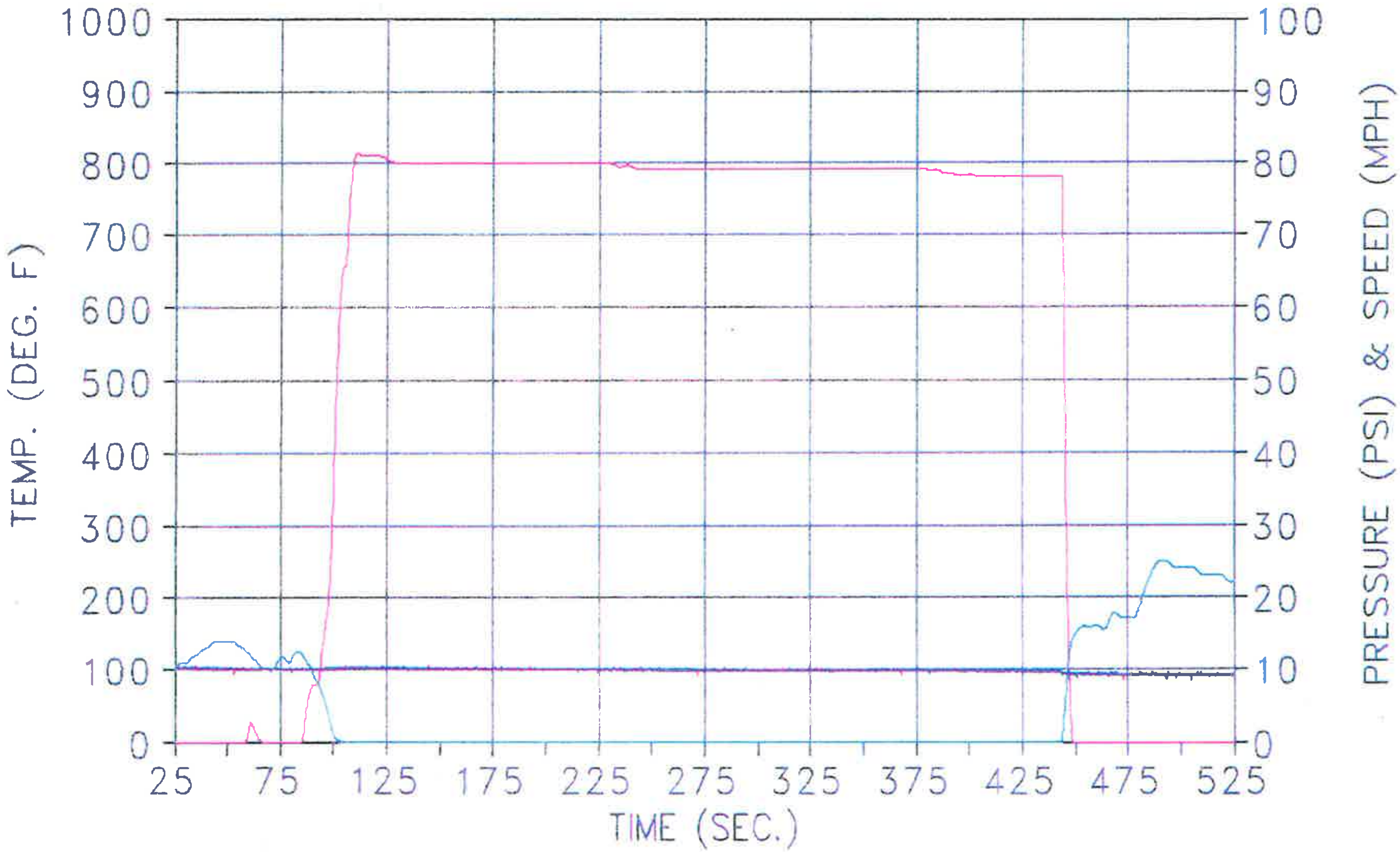


KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

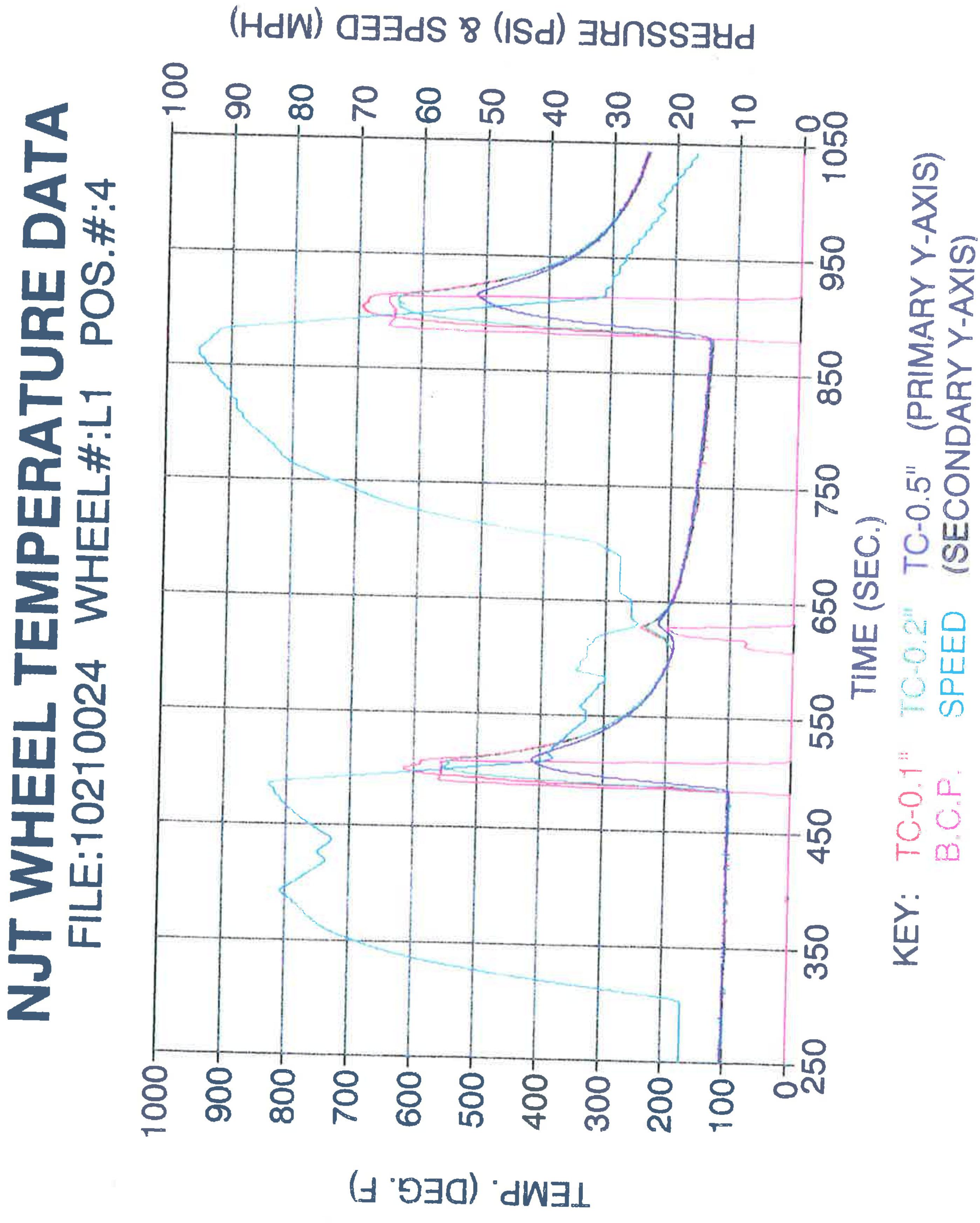

NJT WHEEL TEMPERATURE DATA
FILE:102023358 WHEEL#:L2 POS.#:6
TEMP. (DEG. F)
PRESSURE (PSI) & SPEED (MPH)
0
100
200
300
400
500
600
700
800
900
1000
10
20
30
40
50
60
70
80
90
100
25
75
125
175
225
275
325
375
425
475
525
TIME (SEC.)
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

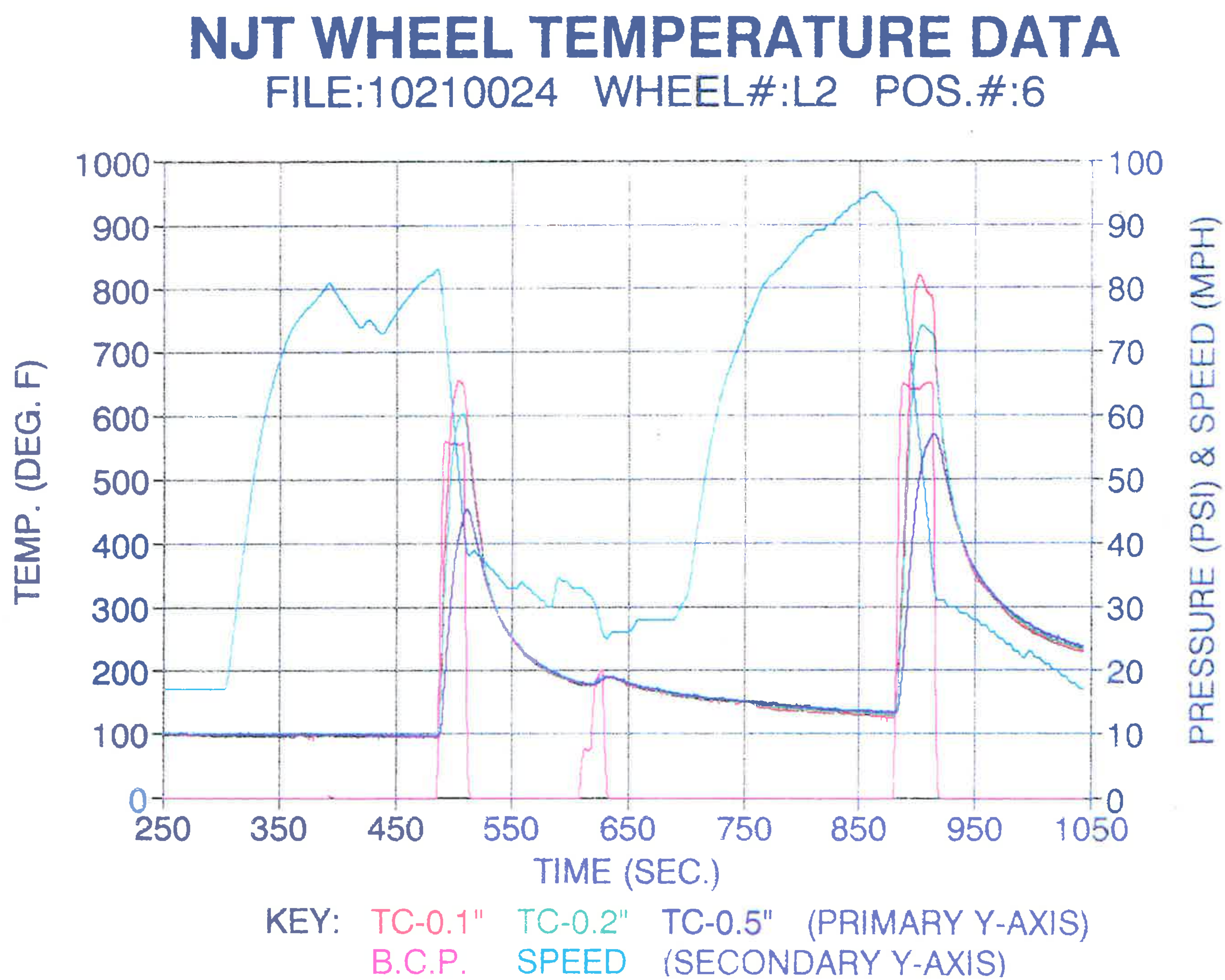
FILE:10202358 WHEEL#:L2 POS.#:7

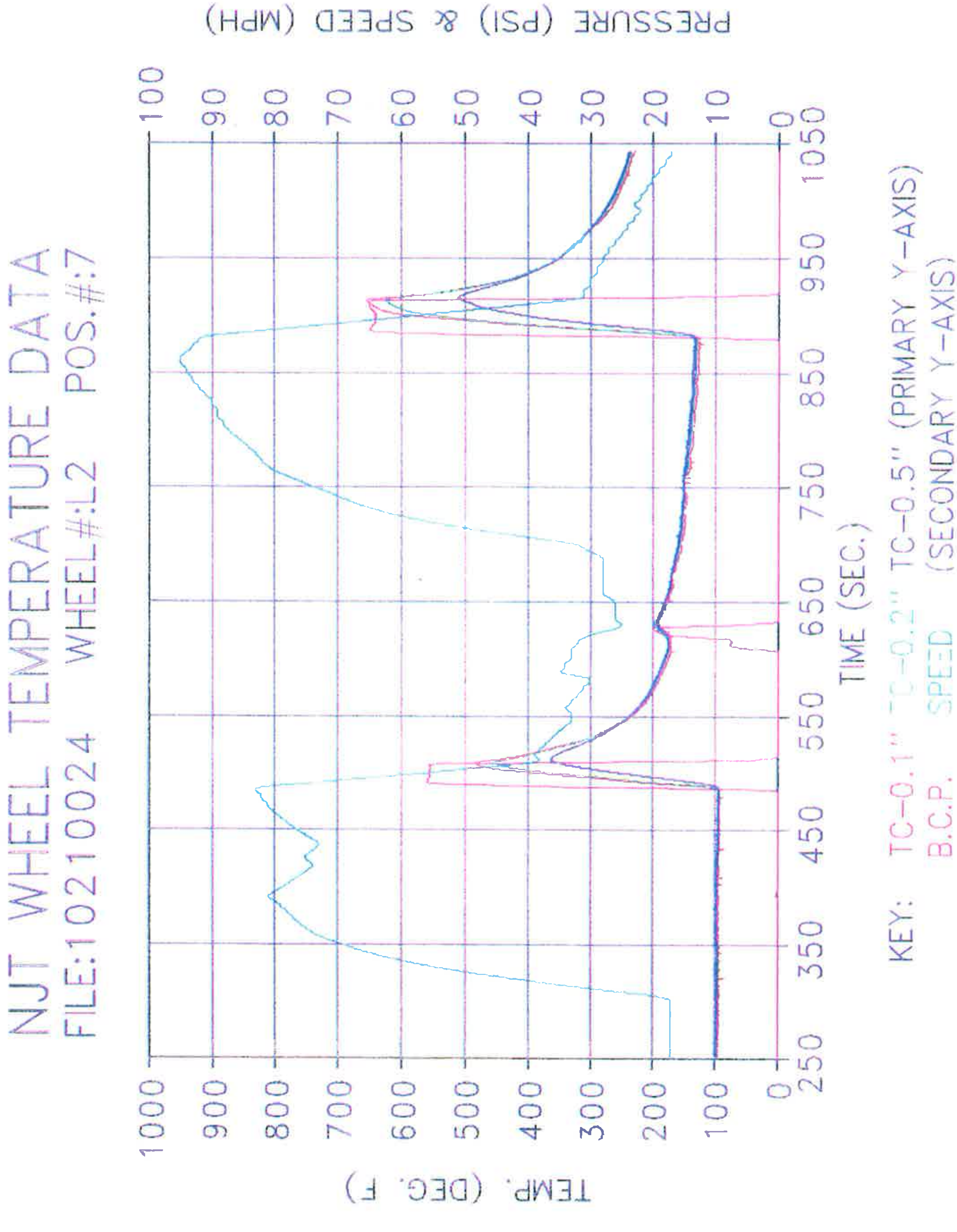


KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)



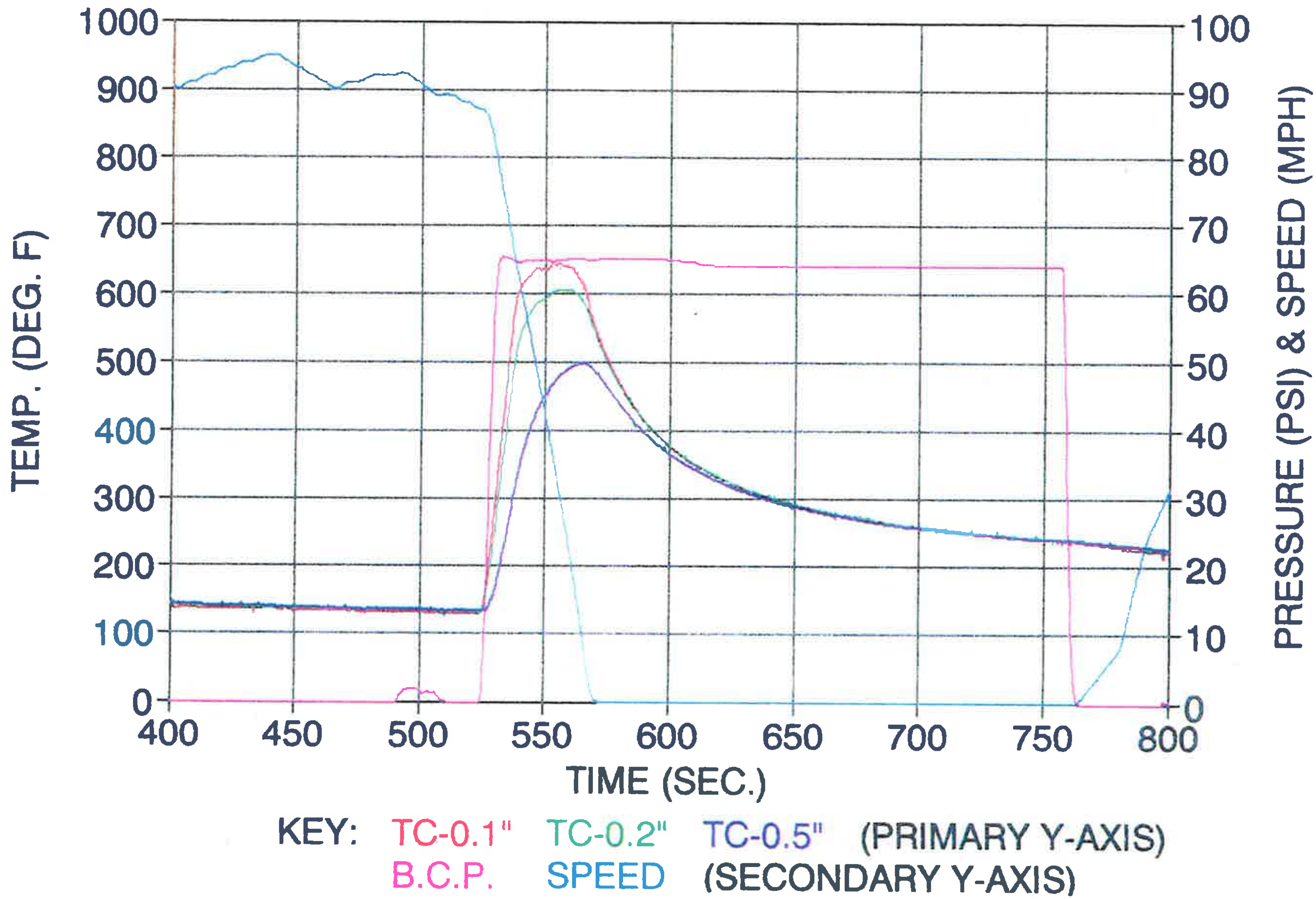
NJT WHEEL TEMPERATURE DATA
FILE:10210024 WHEEL#:L1 POS.#:4
PRESSURE (PSI) & SPEED (MPH)
TEMP. (DEG. F)
TIME (SEC.)
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)


NJT WHEEL TEMPERATURE DATA
FILE:10210024 WHEEL#:L2 POS.#:6
TEMP. (DEG. F)
PRESSURE (PSI) & SPEED (MPH)
1000
900
800
700
600
500
400
300
200
100
0
100
90
80
70
60
50
40
30
20
10
0
250
350
450
550
650
750
850
950
1050
TIME (SEC.)
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)


NJT WHEEL TEMPERATURE DATA
FILE:10210024 WHEEL#:L2 POS.#:7
TEMP. (DEG. F)
PRESSURE (PSI) & SPEED (MPH)
TIME (SEC.)
0
100
200
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60
70
80
90
100
250
350
450
550
650
750
850
950
1050
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

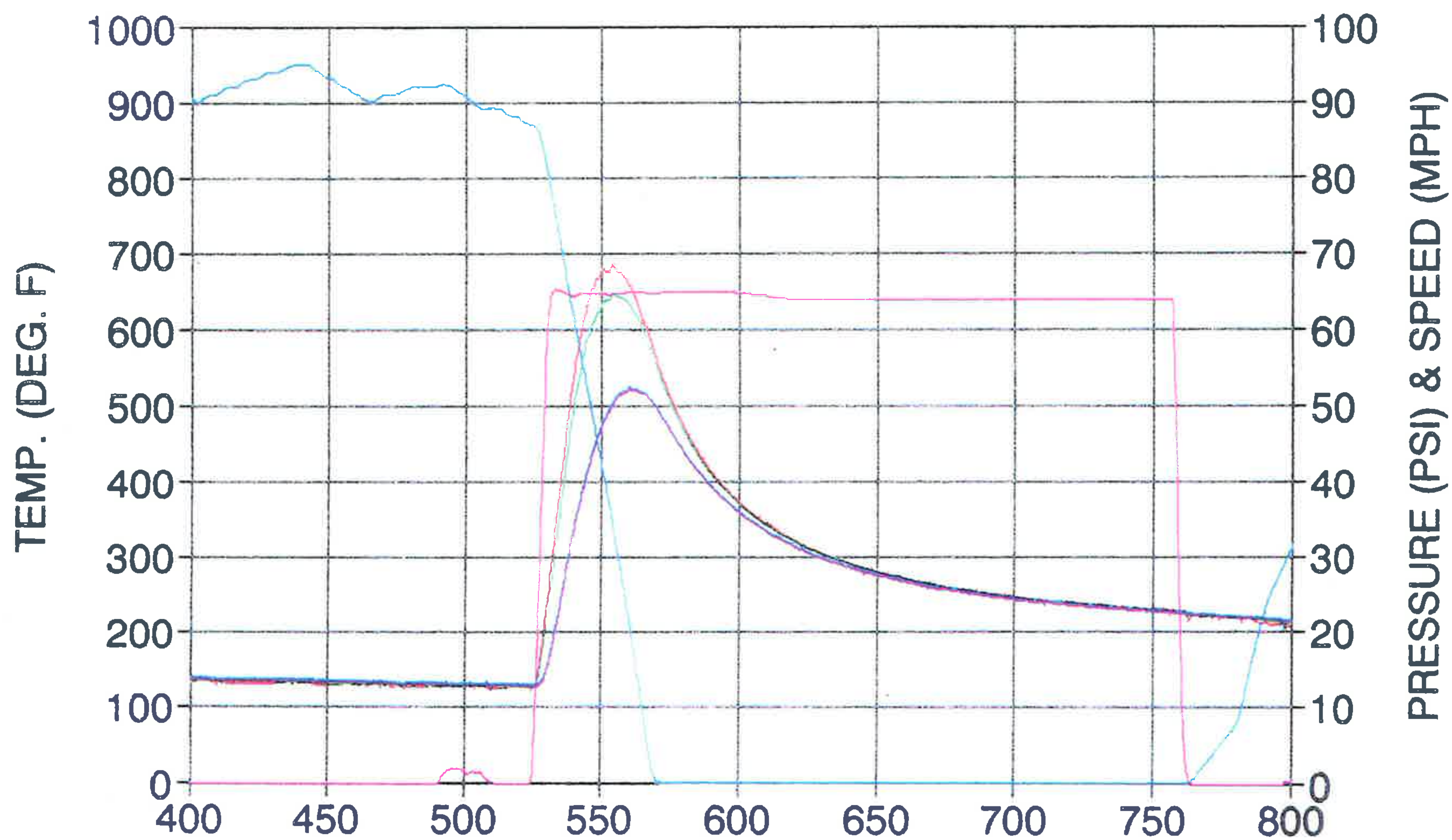
NJT WHEEL TEMPERATURE DATA

FILE:10210053 WHEEL#:L1 POS.#:4

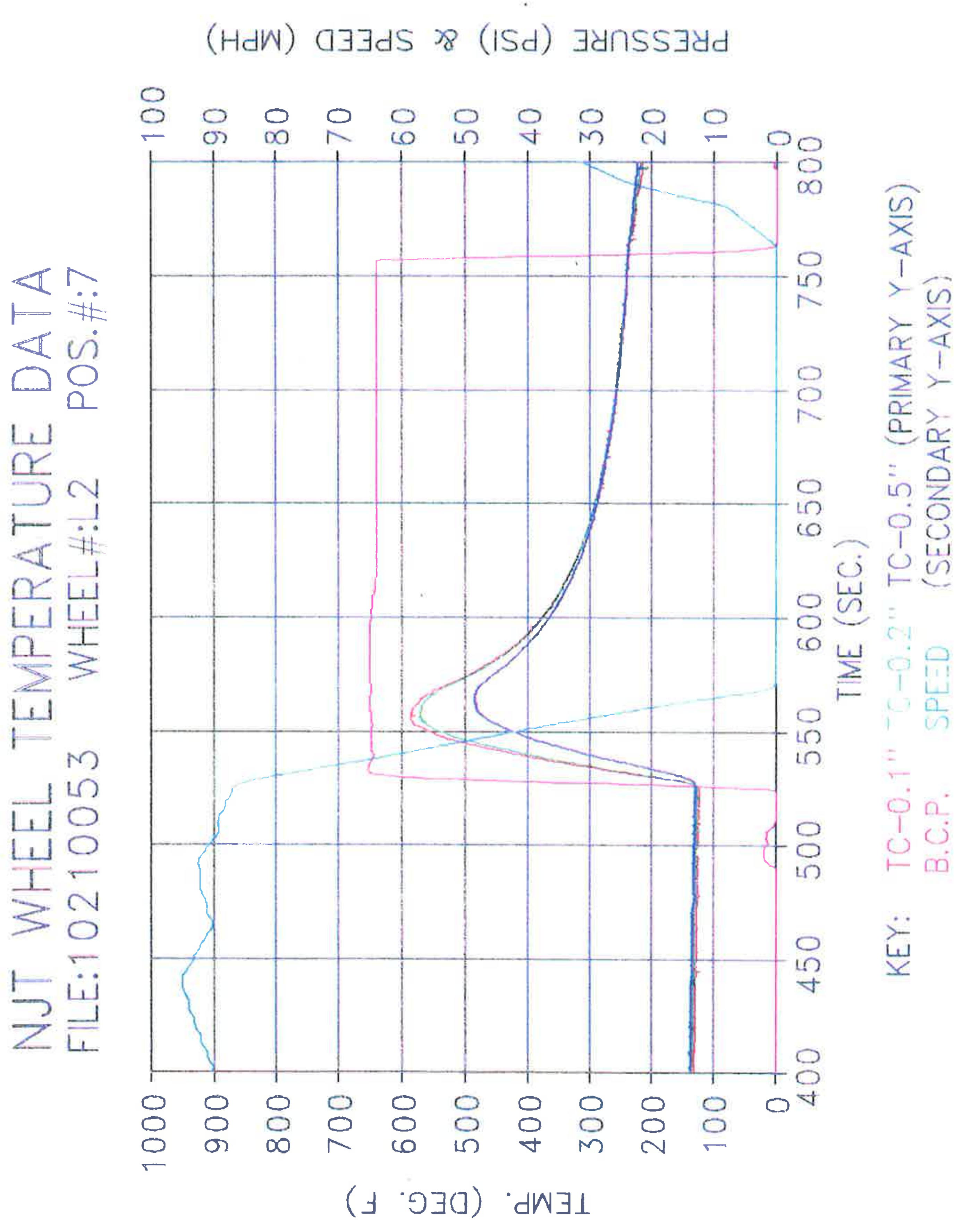


NJT WHEEL TEMPERATURE DATA

FILE:10210053 WHEEL#:L2 POS.#:6

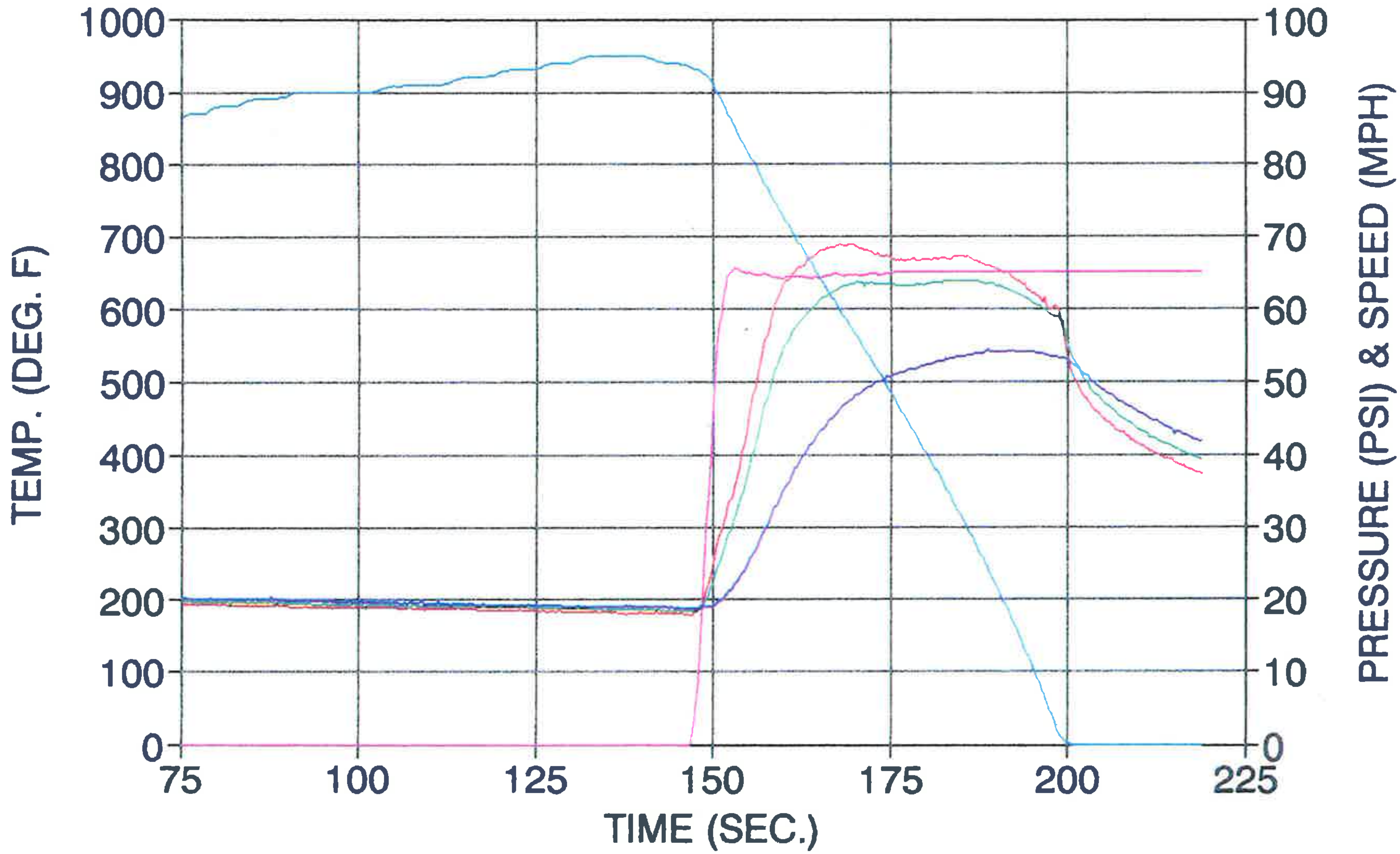


KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)


NJT WHEEL TEMPERATURE DATA
FILE:10210053 WHEEL#:L2 POS.#:7
PRESSURE (PSI) & SPEED (MPH)
TEMP. (DEG. F)
TIME (SEC.)
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

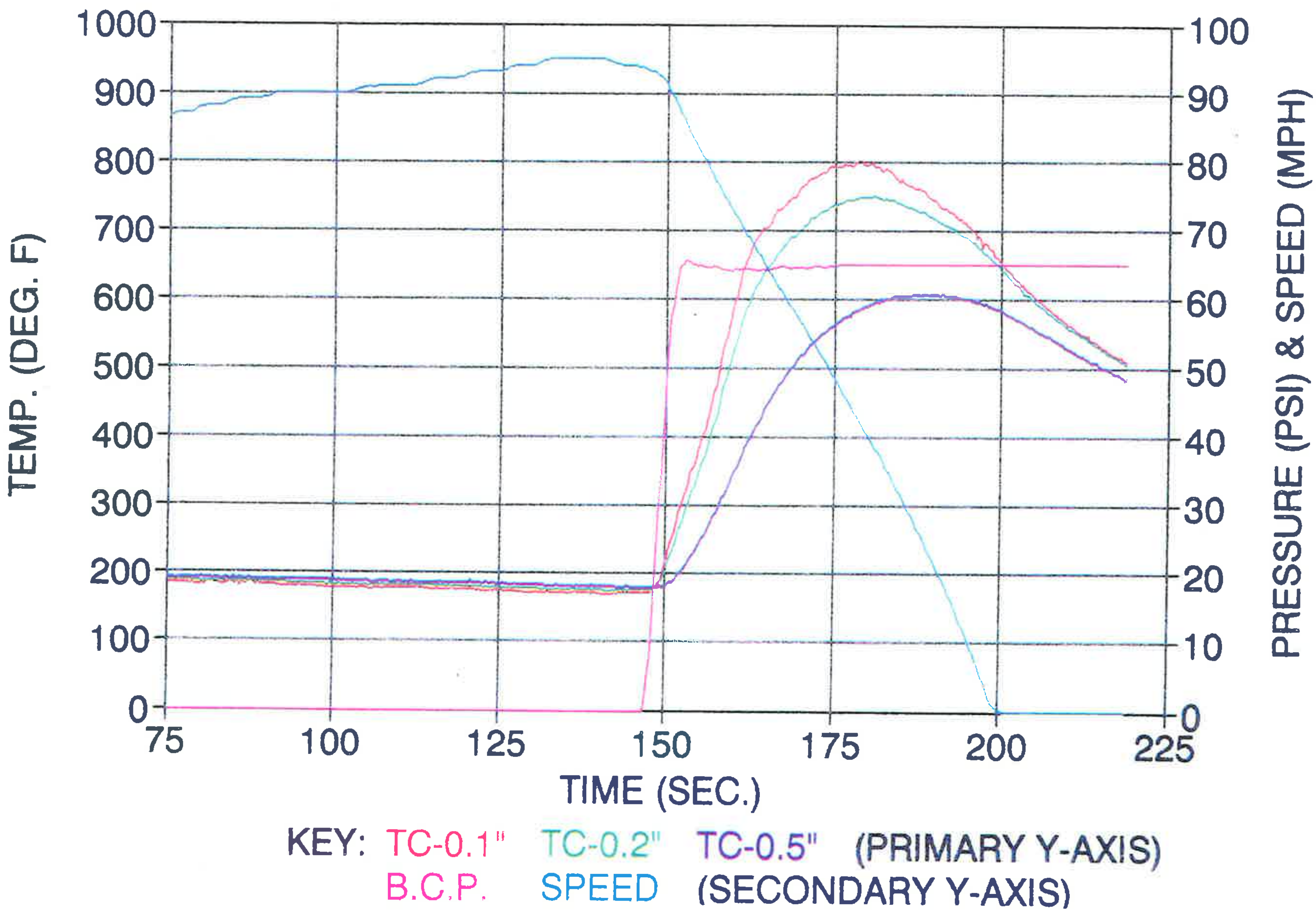
FILE:10210107 WHEEL#:L1 POS.#:4

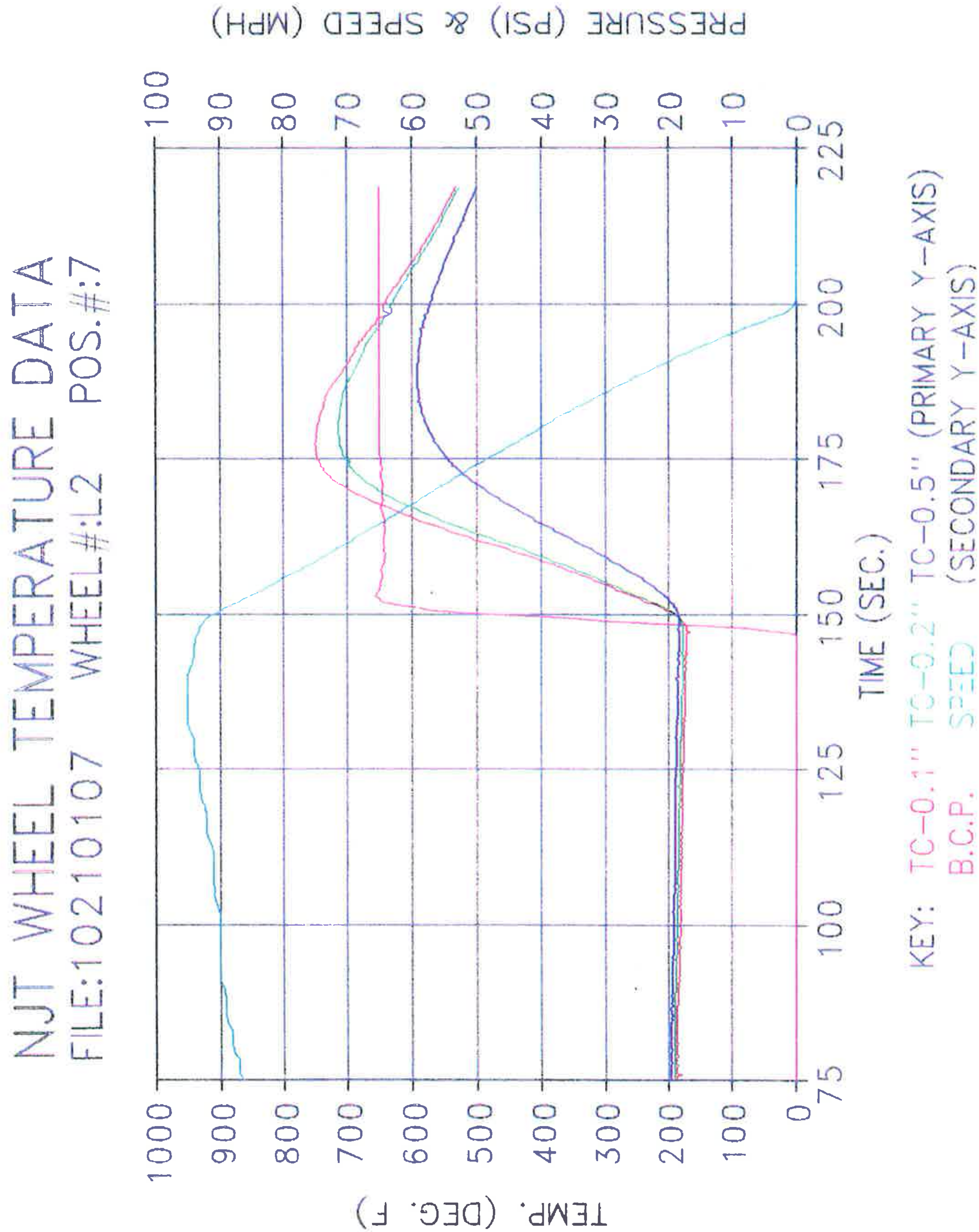


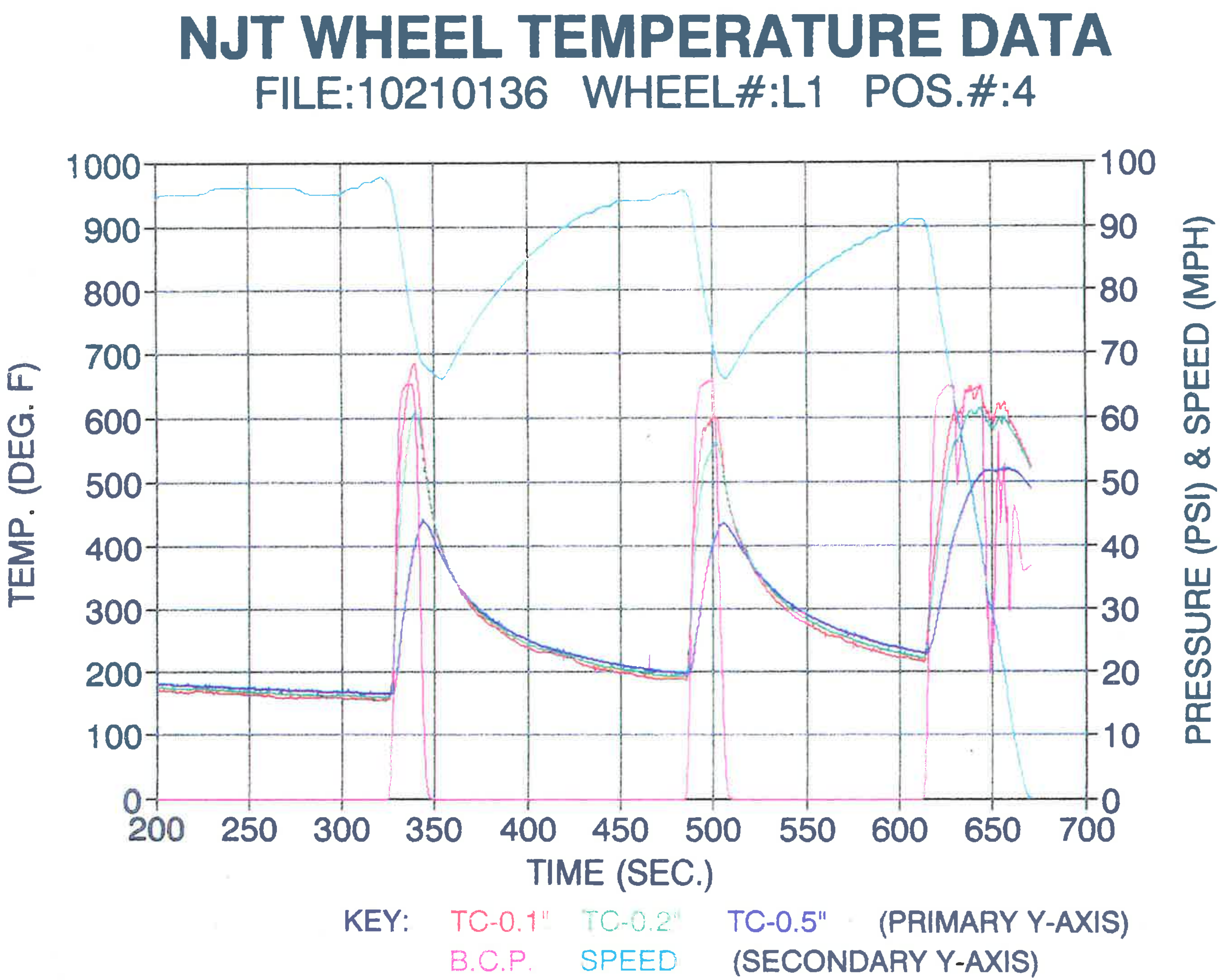
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

FILE:10210107 WHEEL#:L2 POS.#:6



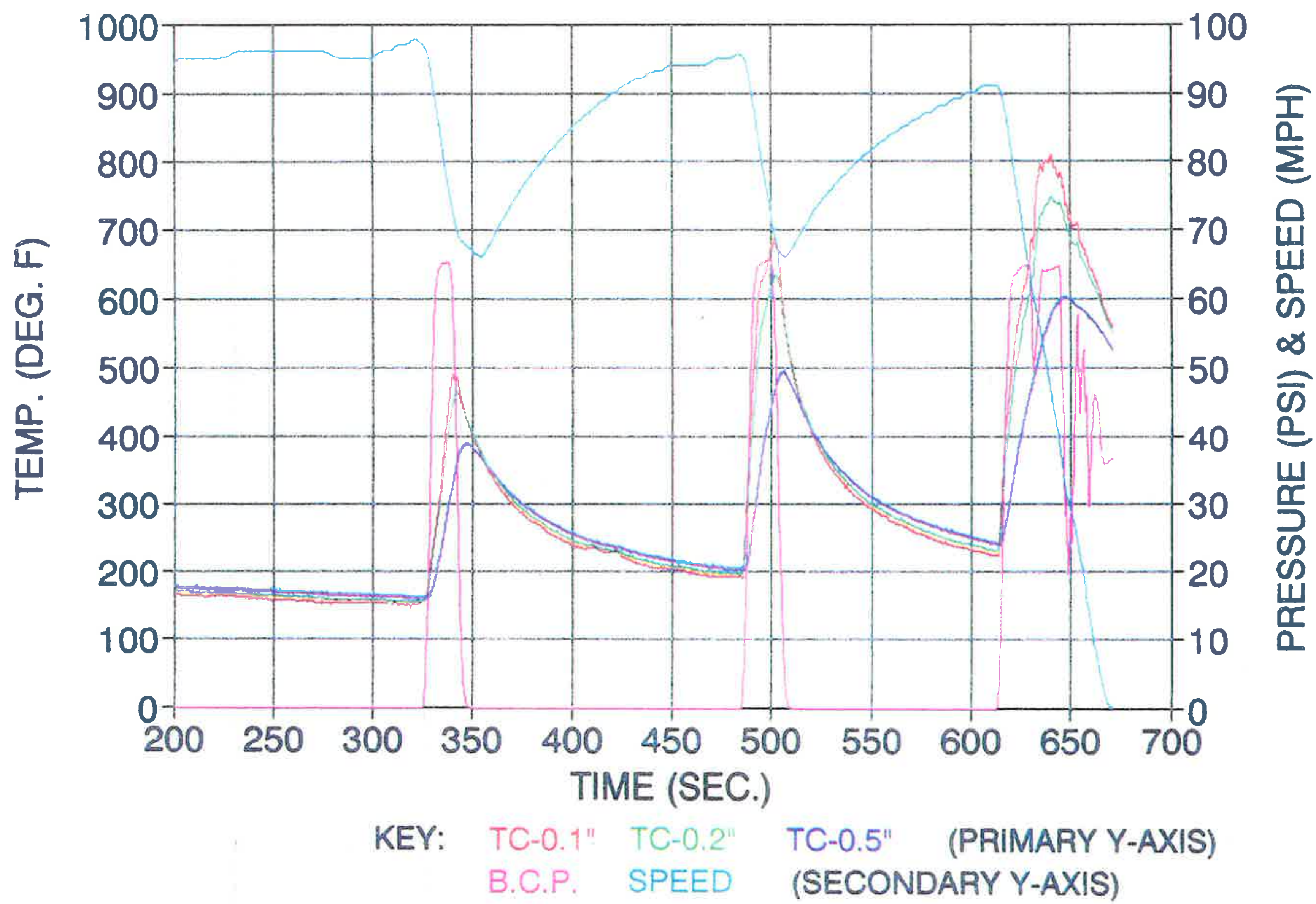

NJT WHEEL TEMPERATURE DATA
FILE:10210107 WHEEL#:L2 POS.#:7
PRESSURE (PSI) & SPEED (MPH)
TEMP. (DEG. F)
TIME (SEC.)
75
100
125
150
175
200
225
0
100
200
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60
70
80
90
100
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

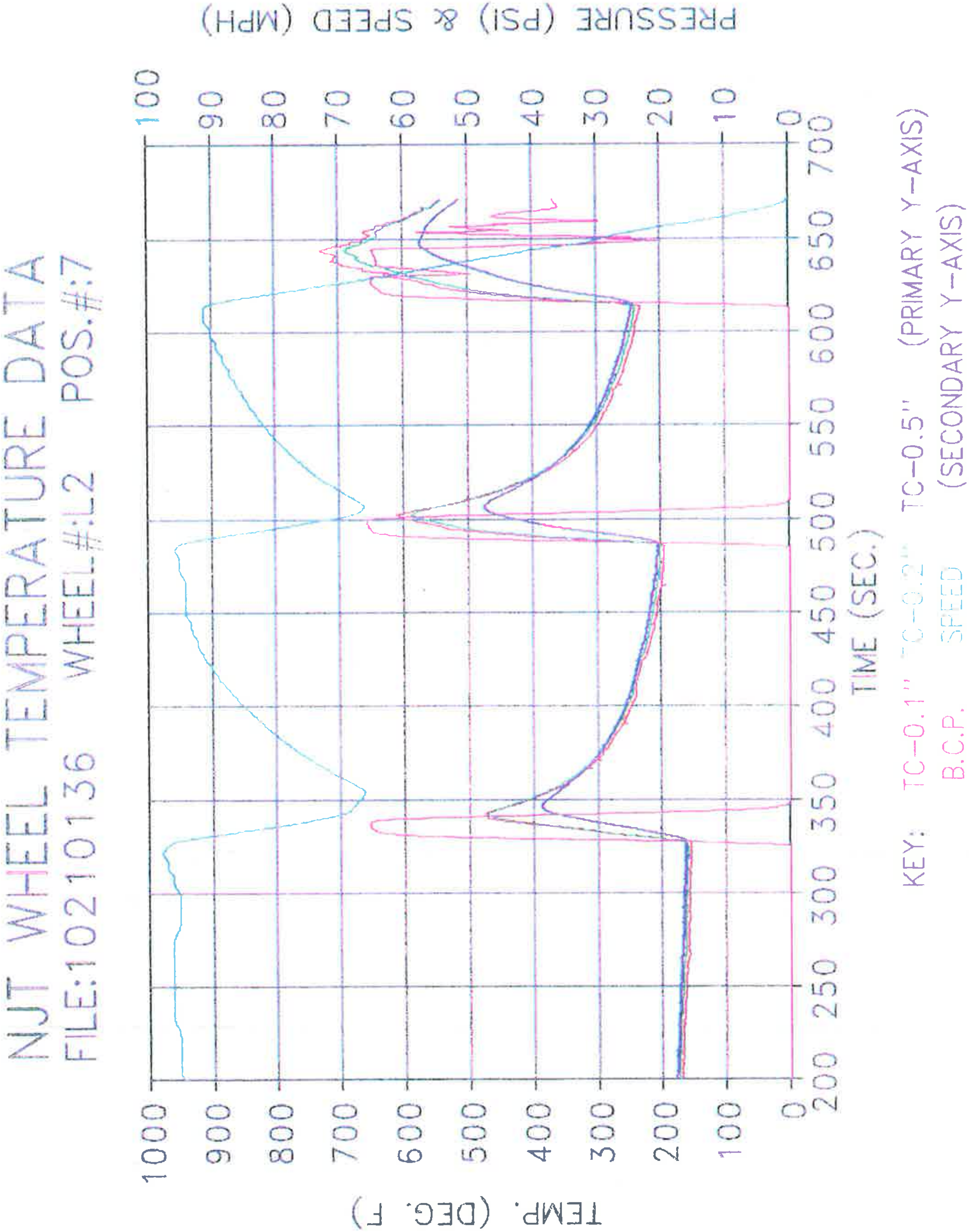


NJT WHEEL TEMPERATURE DATA
FILE:10210136 WHEEL#:L1 POS.#:4
1000
900
800
700
600
500
400
300
200
100
0
TEMP. (DEG. F)
100
90
80
70
60
50
40
30
20
10
0
PRESSURE (PSI) & SPEED (MPH)
200
250
300
350
400
450
500
550
600
650
700
TIME (SEC.)
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

FILE:10210136 WHEEL#:L2 POS.#:6

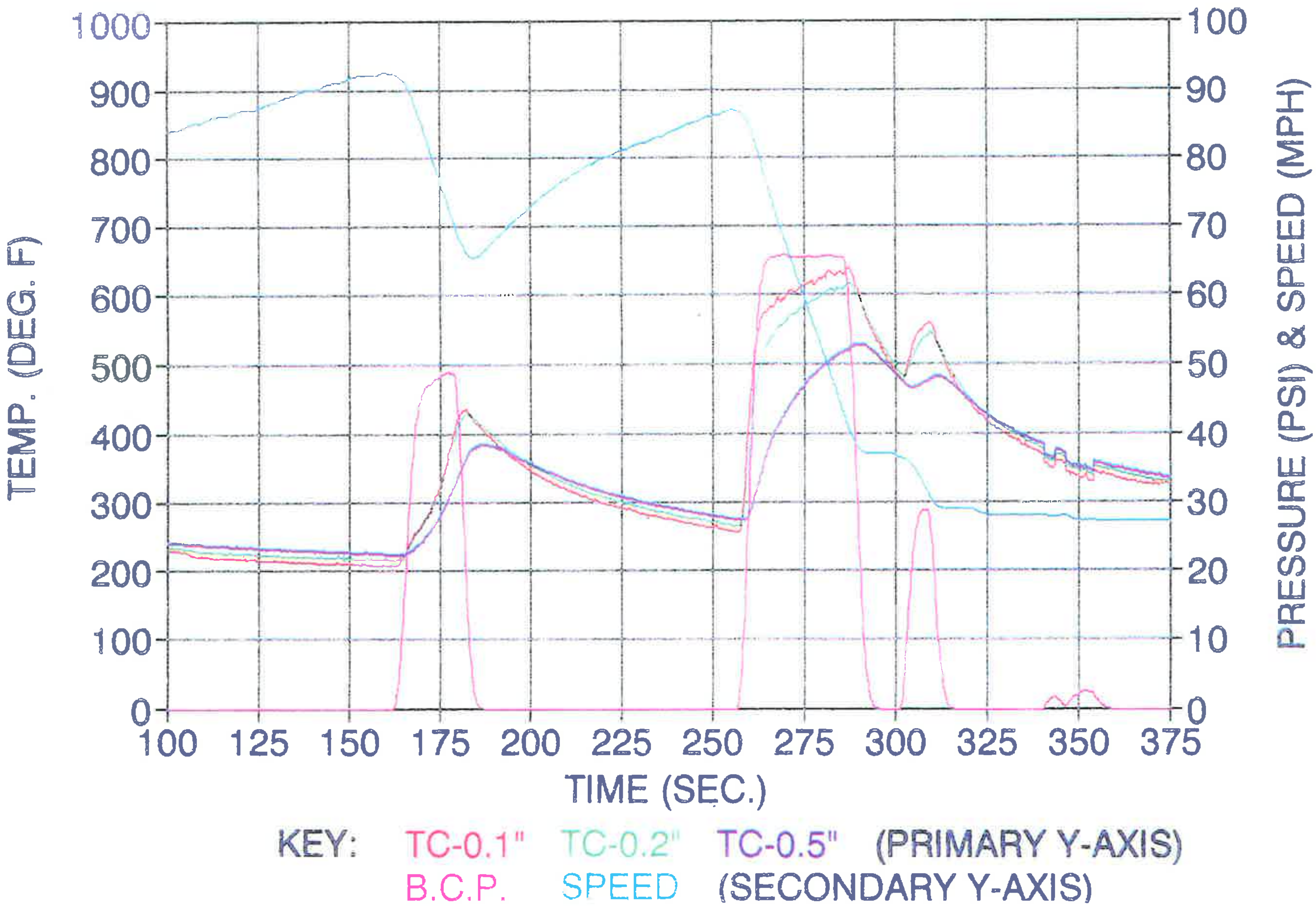




NJT WHEEL TEMPERATURE DATA
FILE:10210136 WHEEL #:L2 POS.#:7
PRESSURE (PSI) & SPEED (MPH)
TEMP. (DEG. F)
TIME (SEC.)
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

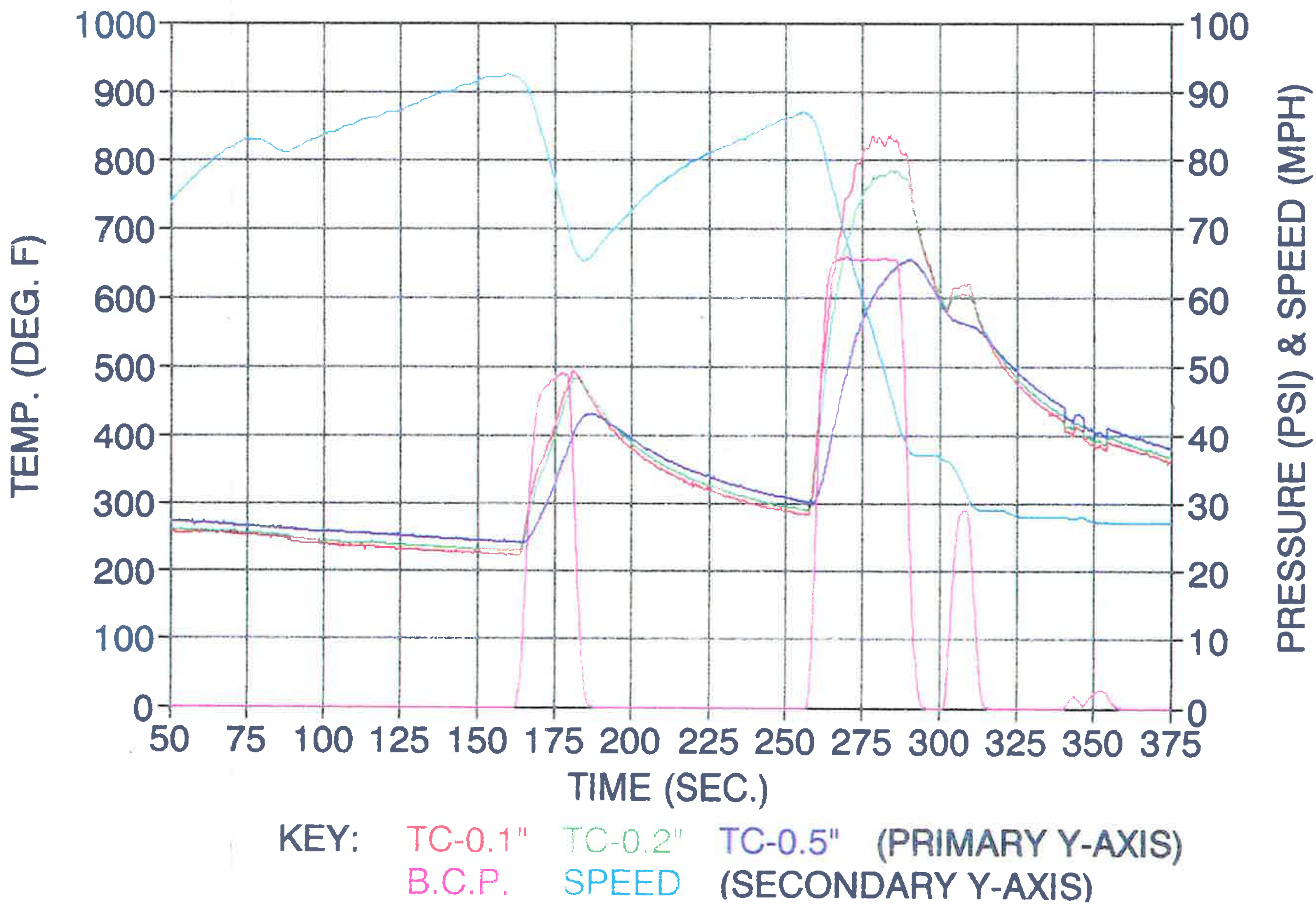
NJT WHEEL TEMPERATURE DATA

FILE:10210202 WHEEL#:L1 POS.#:4



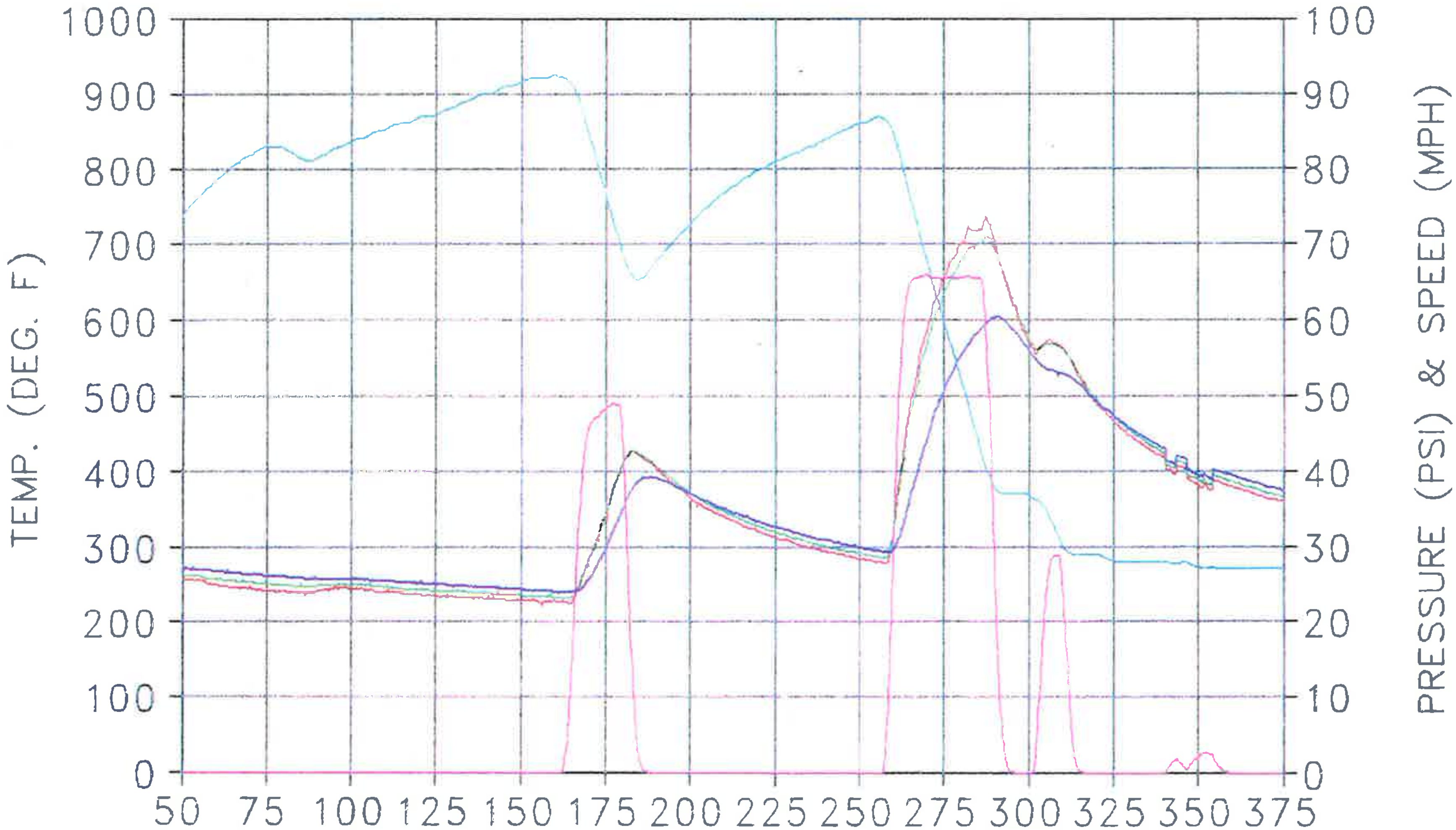
NJT WHEEL TEMPERATURE DATA

FILE:10210202 WHEEL#:L2 POS.#:6

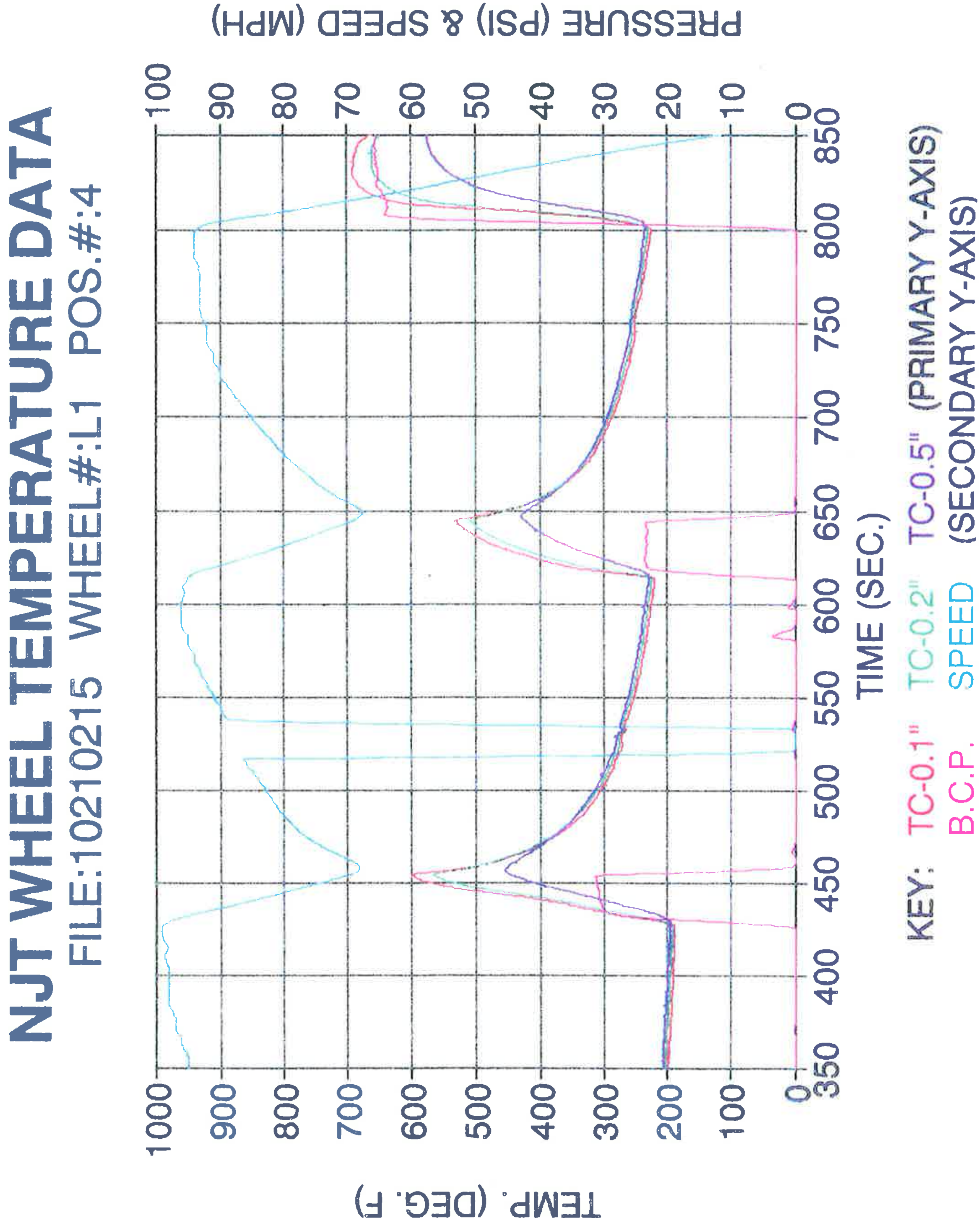


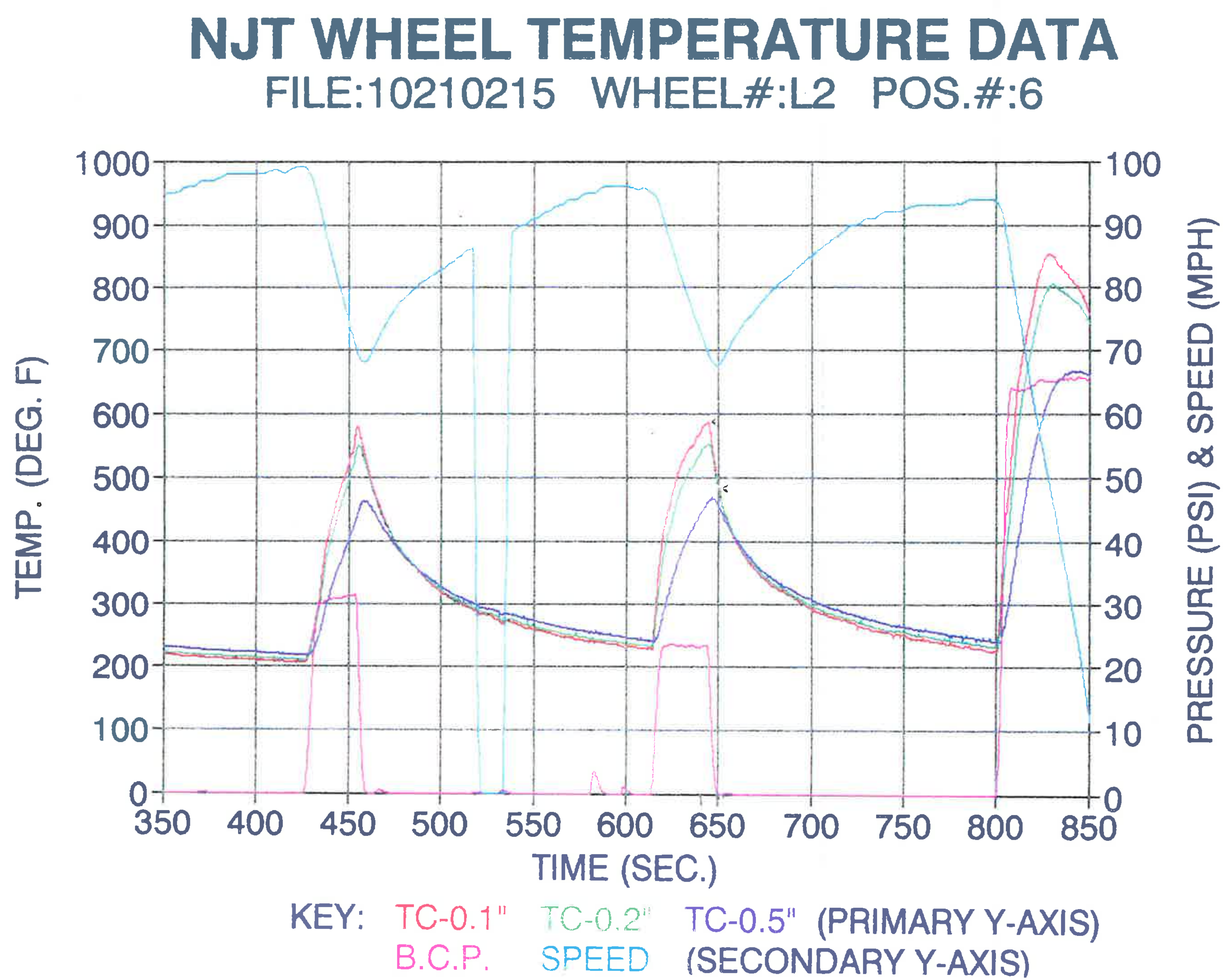
NJT WHEEL TEMPERATURE DATA

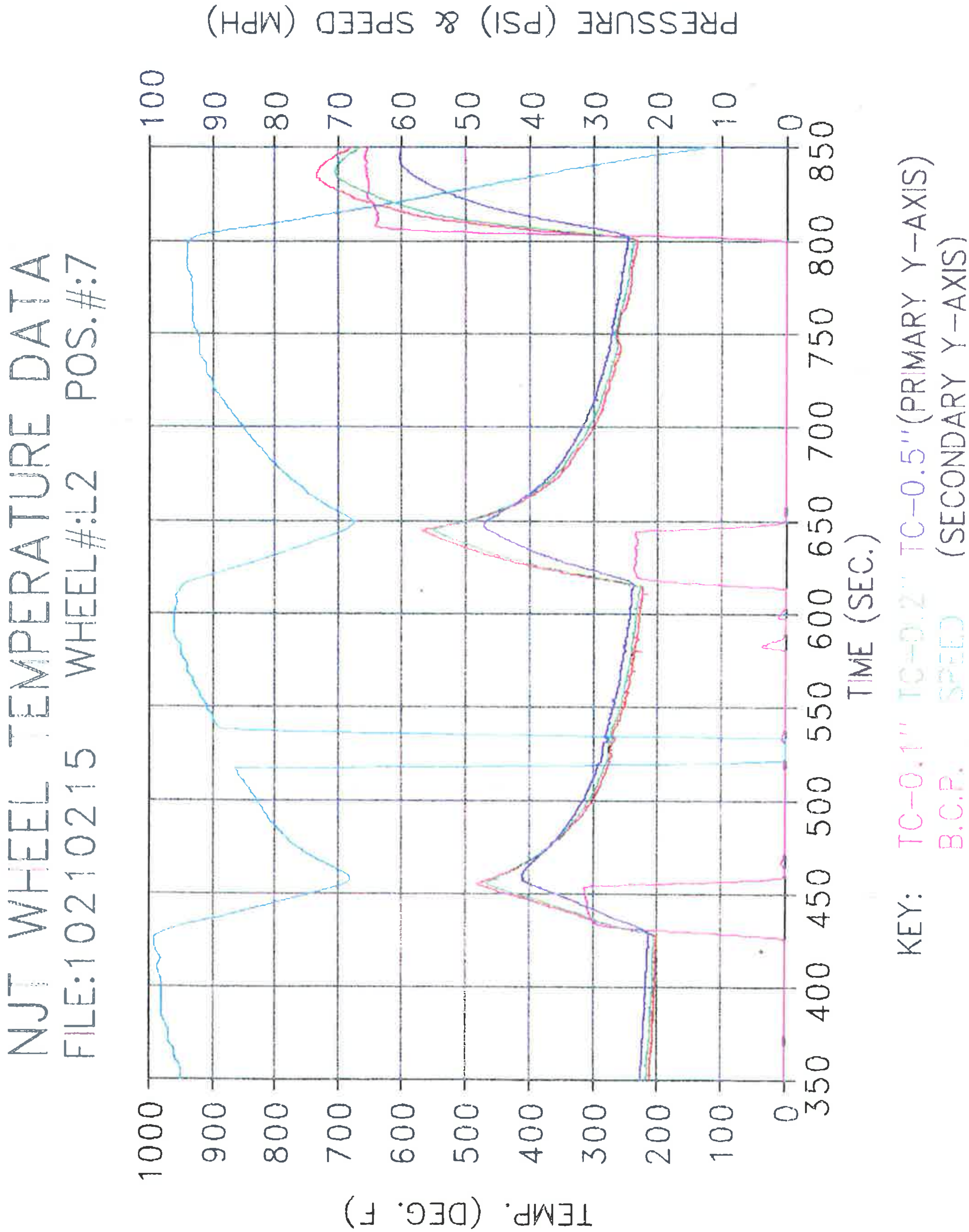
FILE:10210202 WHEEL#:L2 POS.#:7

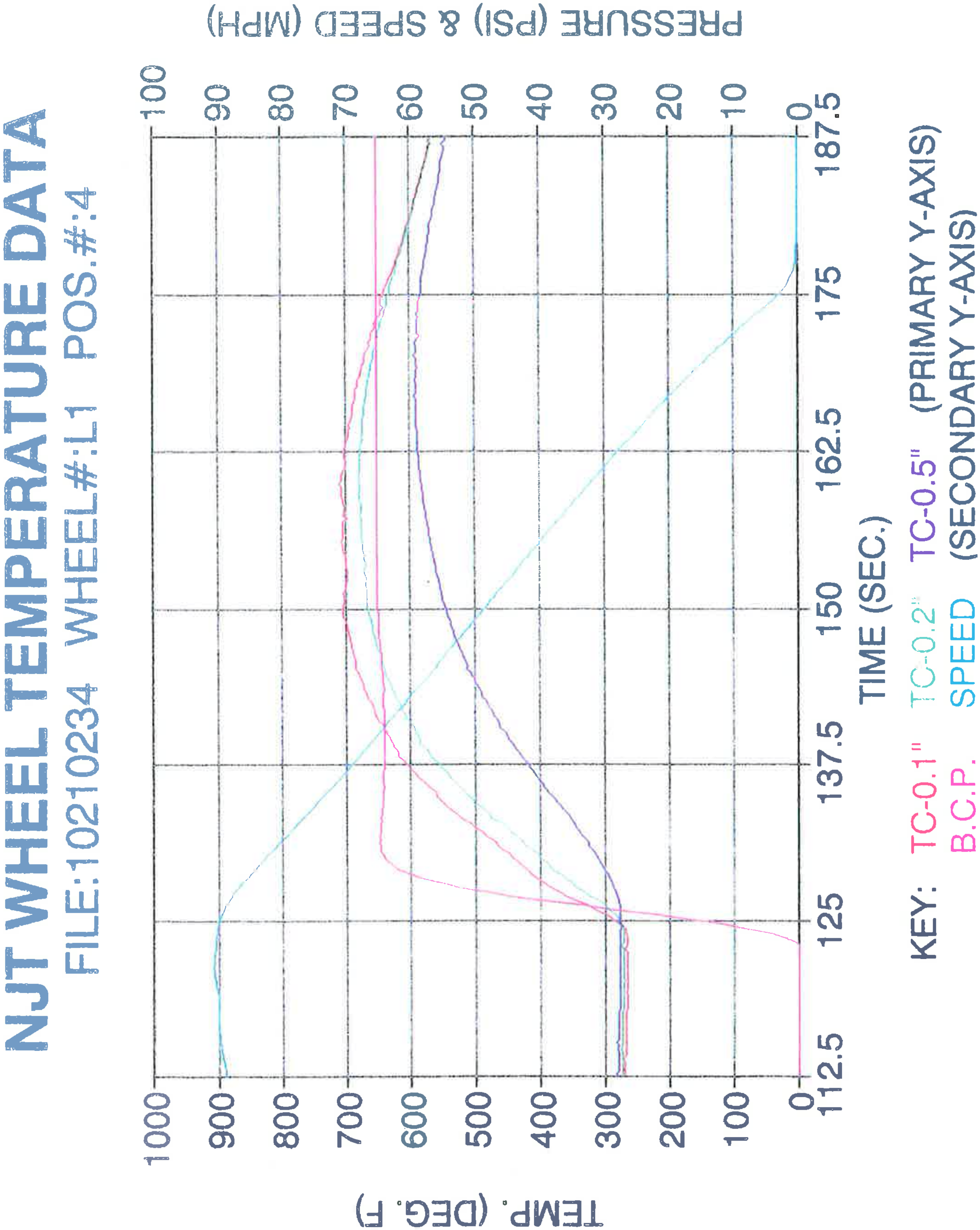


KEY: TC–0.1" TC–0.2" TC–0.5" (PRIMARY Y–AXIS)
B.C.P. SPEED (SECONDARY Y–AXIS)


NJT WHEEL TEMPERATURE DATA
FILE:10210215 WHEEL#:L1 POS.#:4
TEMP. (DEG. F)
PRESSURE (PSI) & SPEED (MPH)
TIME (SEC.)
0
100
200
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60
70
80
90
100
350
400
450
500
550
600
650
700
750
800
850
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

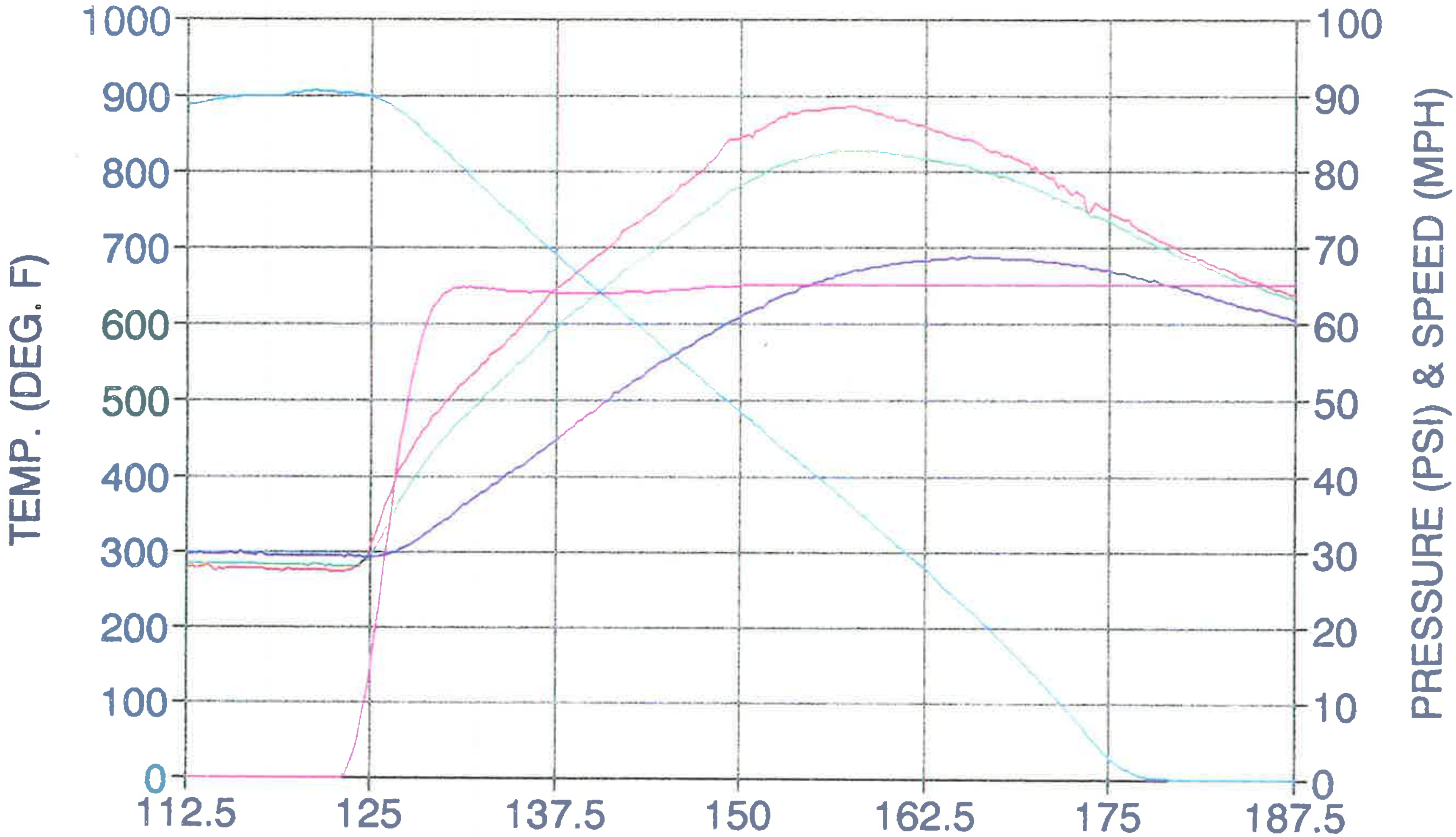

NJT WHEEL TEMPERATURE DATA
FILE:10210215 WHEEL#:L2 POS.#:6
TEMP. (DEG. F)
1000
900
800
700
600
500
400
300
200
100
0
PRESSURE (PSI) & SPEED (MPH)
100
90
80
70
60
50
40
30
20
10
0
350
400
450
500
550
600
650
700
750
800
850
TIME (SEC.)
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)


NJT WHEEL TEMPERATURE DATA
FILE:10210215 WHEEL#:L2 POS.#:7
PRESSURE (PSI) & SPEED (MPH)
TEMP. (DEG. F)
TIME (SEC.)
KEY: TC-0.1" TC-0.2" TC-0.5"(PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)


NJT WHEEL TEMPERATURE DATA
FILE:10210234 WHEEL#:L1 POS.#:4
PRESSURE (PSI) & SPEED (MPH)
TEMP. (DEG. F)
TIME (SEC.)
112.5
125
137.5
150
162.5
175
187.5
0
100
200
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60
70
80
90
100
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

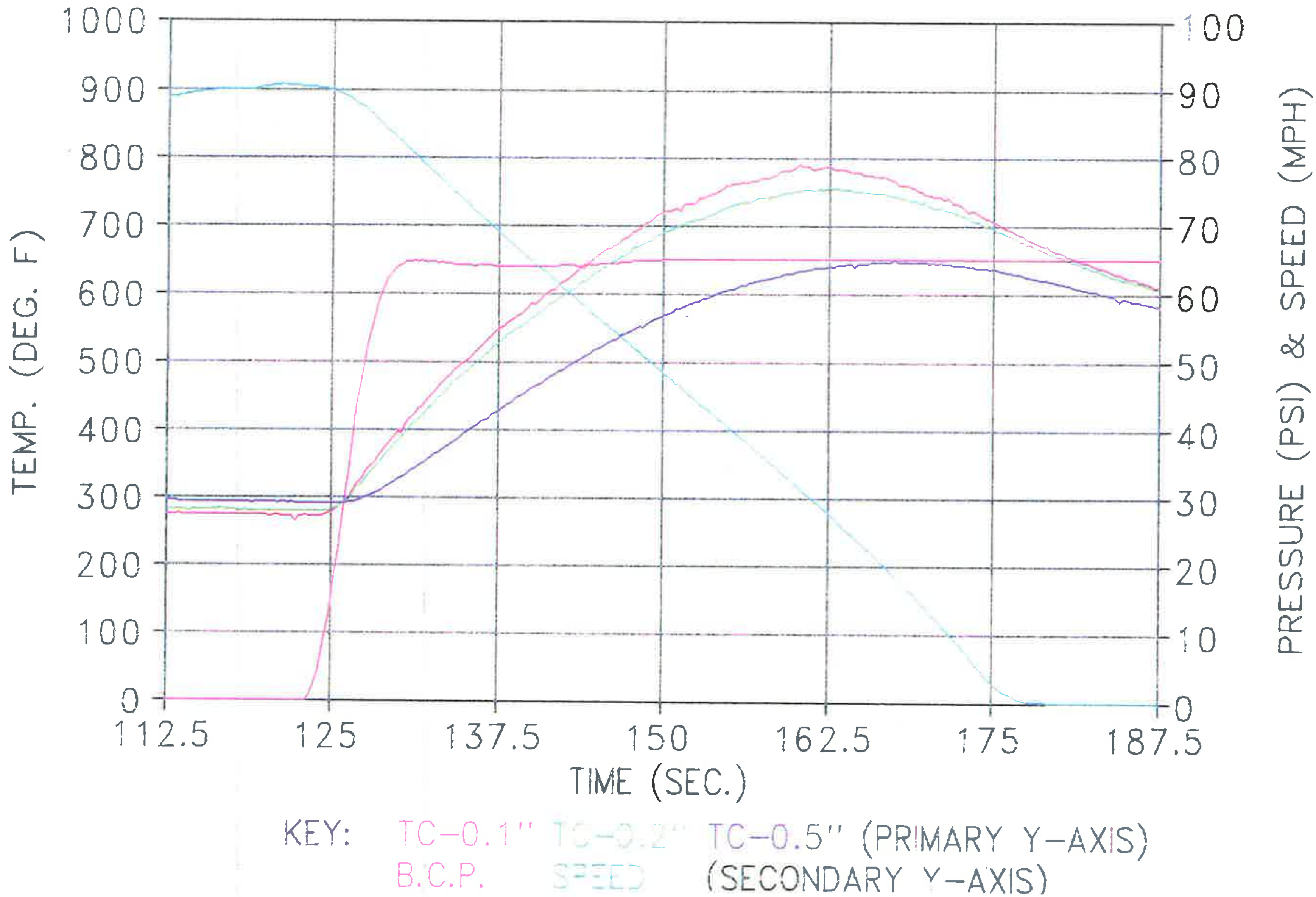
FILE:10210234 WHEEL#:L2 POS.#:6



KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

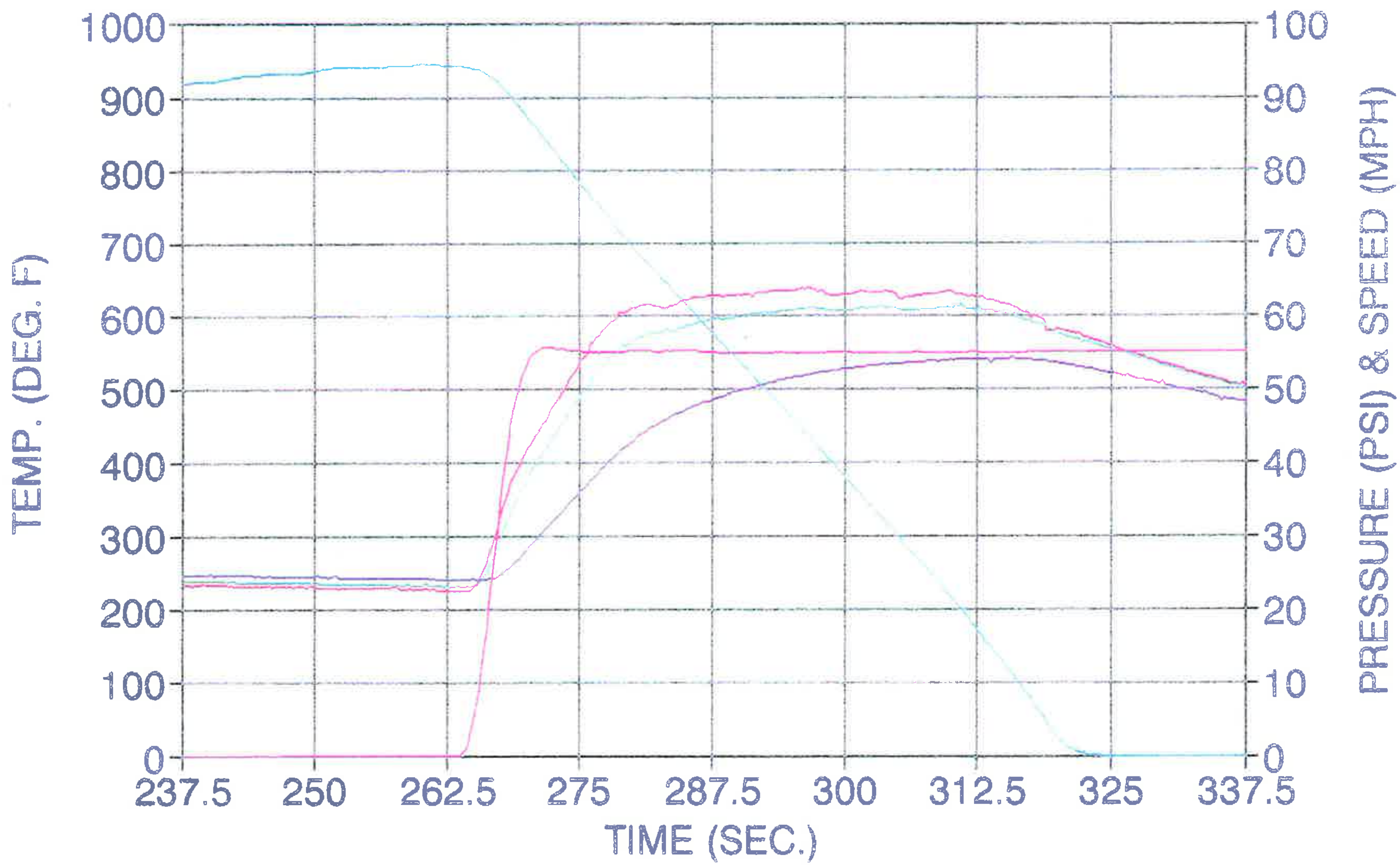
NJT WHEEL TEMPERATURE DATA

FILE:10210234 WHEEL#:L2 POS.#:7



NJT WHEEL TEMPERATURE DATA

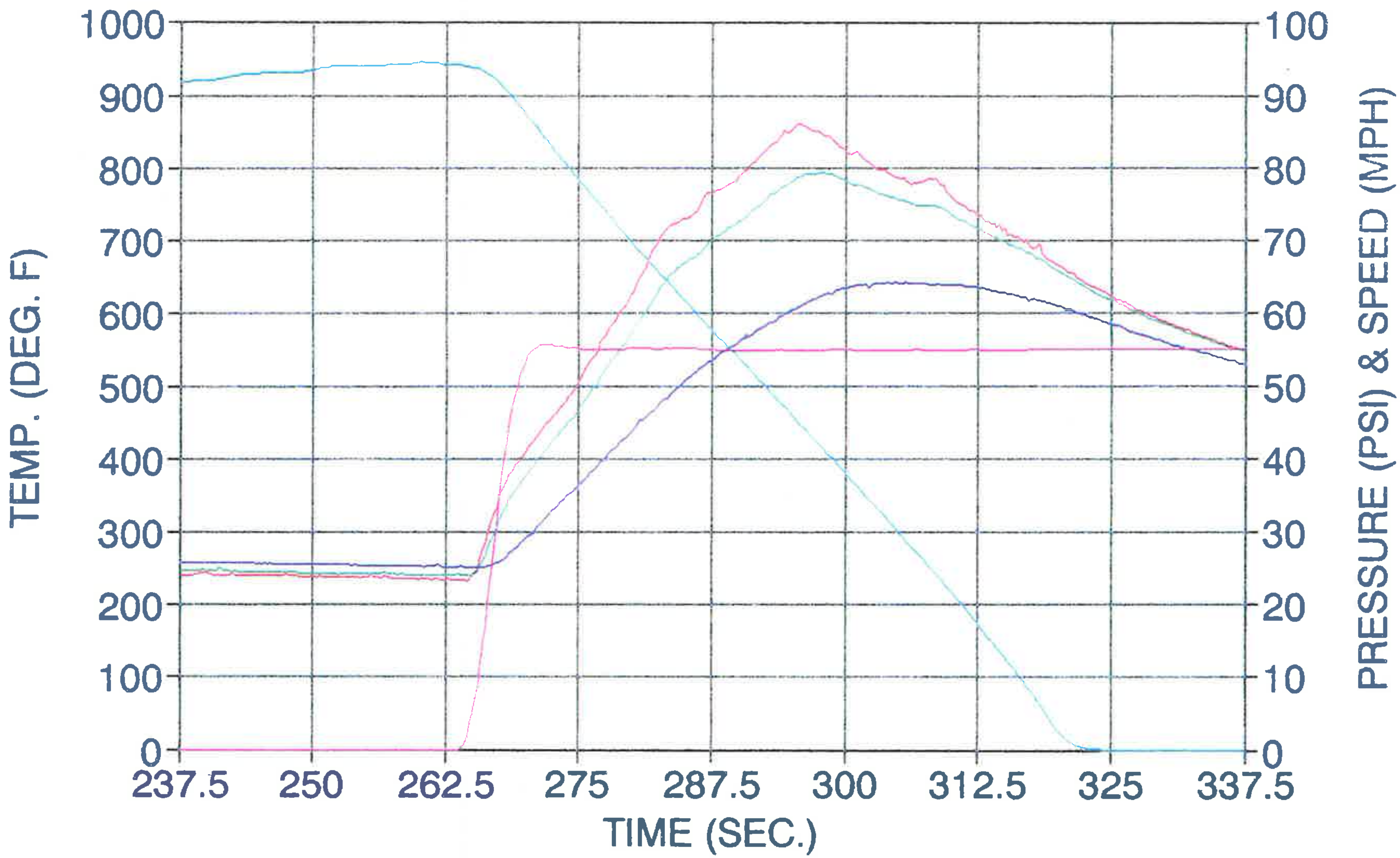
FILE:10210256   WHEEL#:L1   POS.#:4



KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

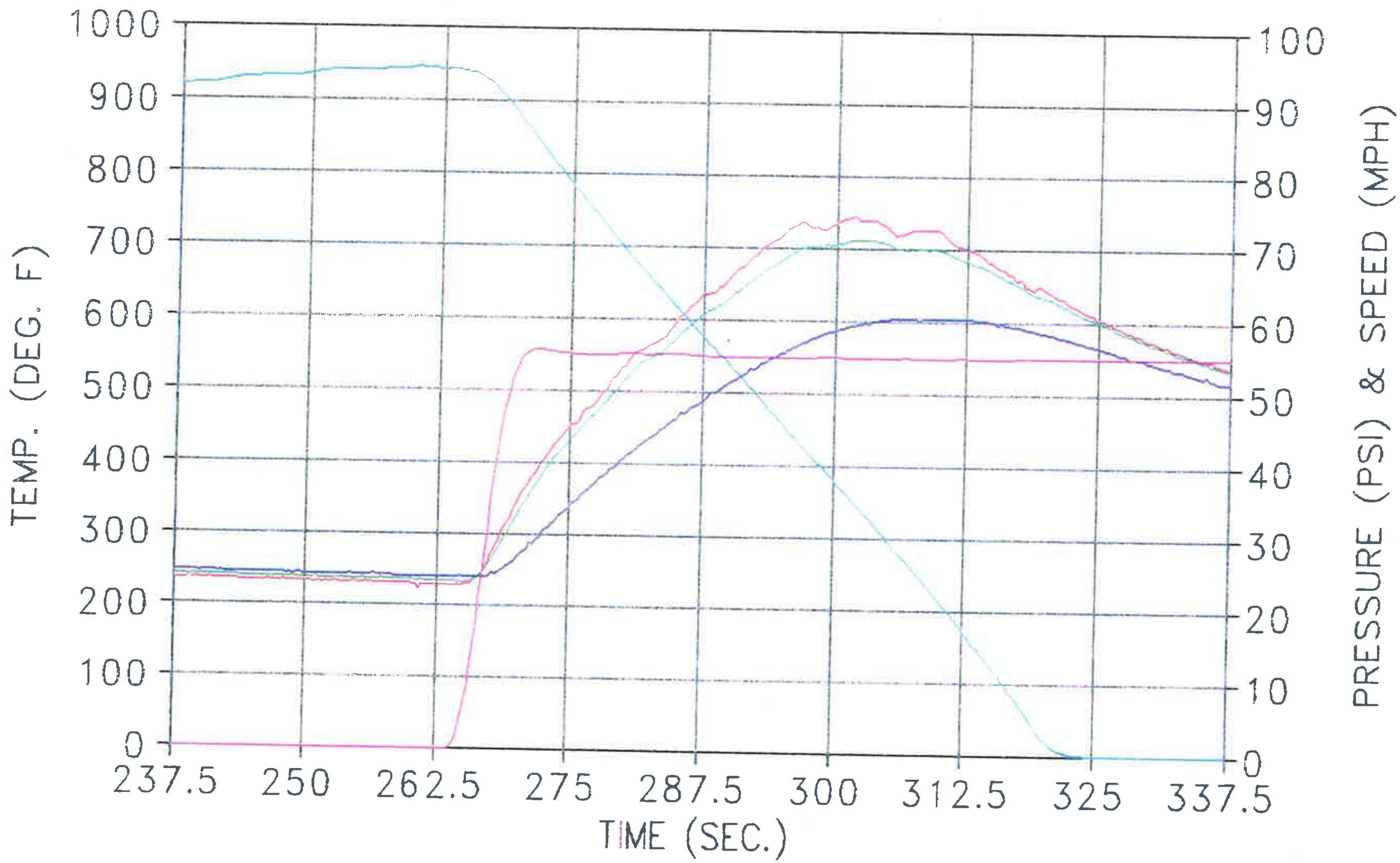
FILE:10210256 WHEEL#:L2 POS.#:6



KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

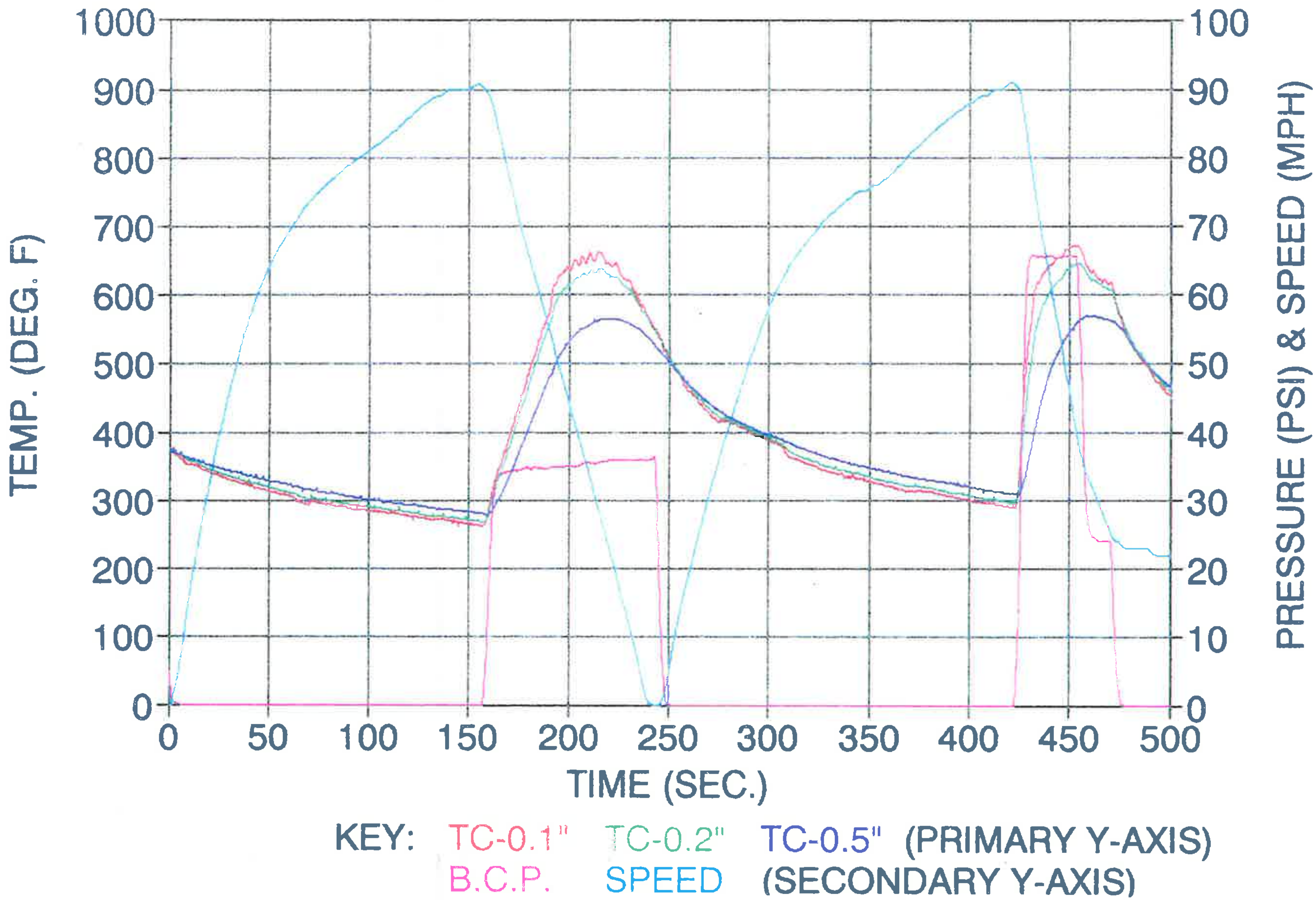
FILE:10210256 WHEEL#:L2 POS.#:7



KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

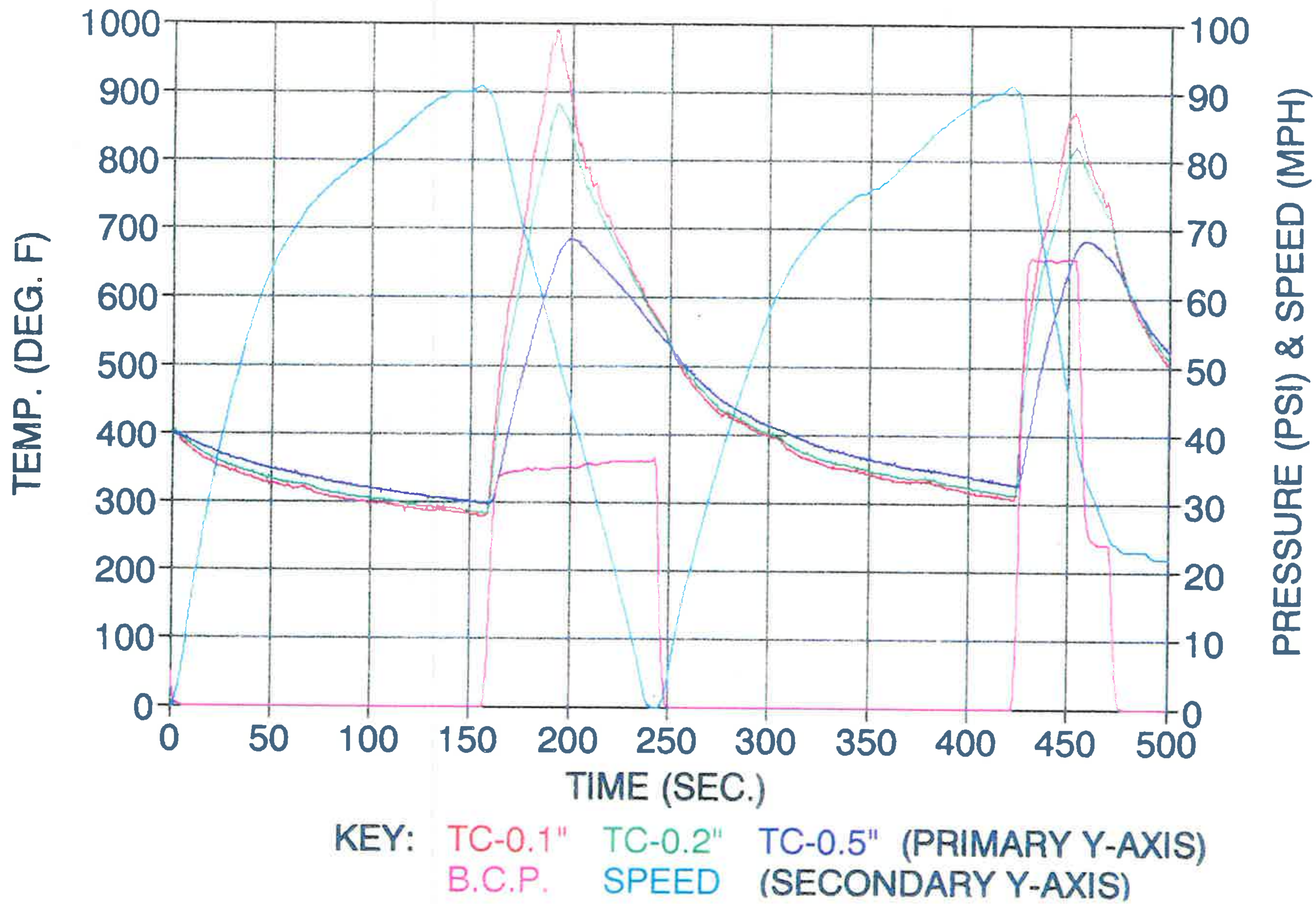
NJT WHEEL TEMPERATURE DATA

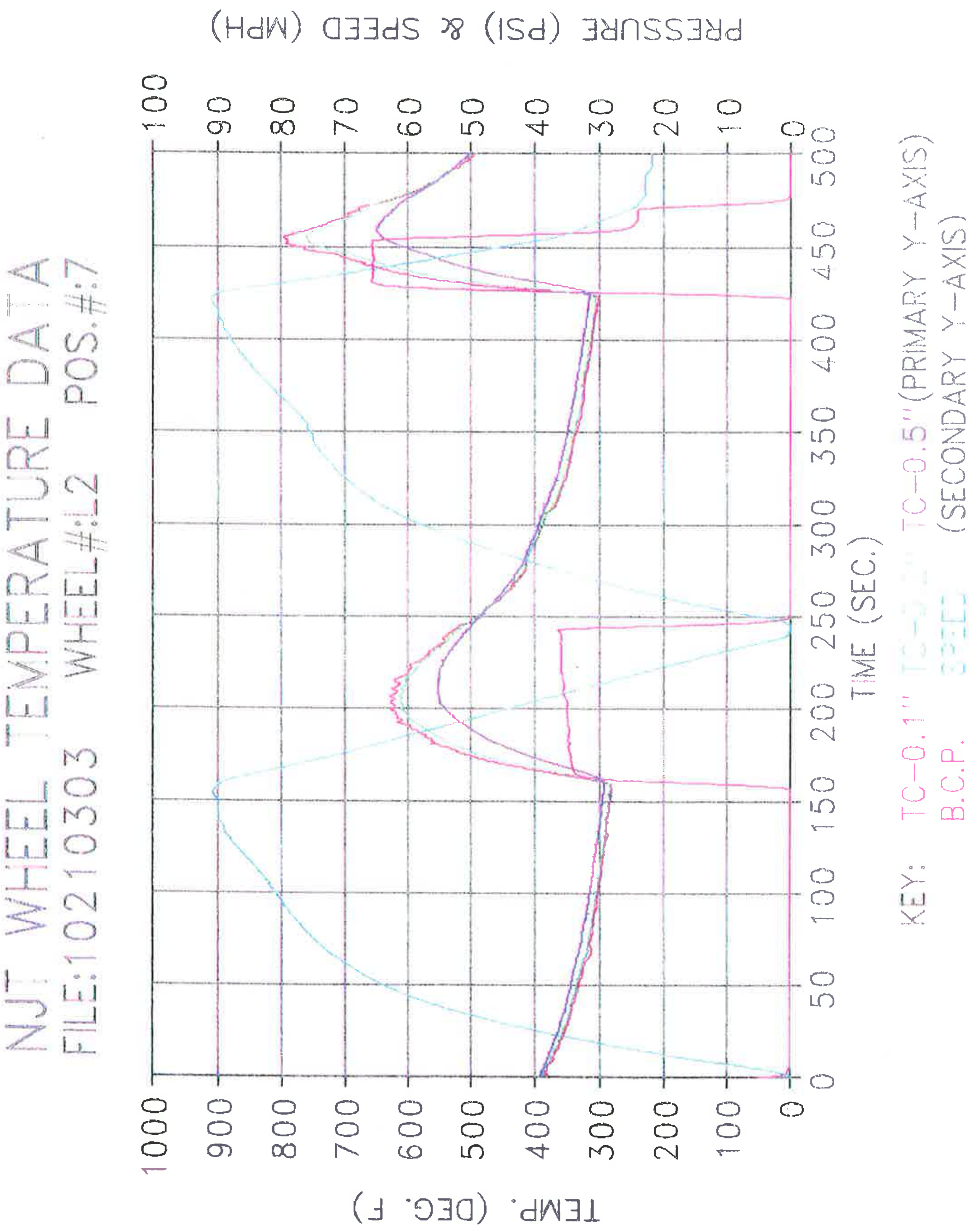
FILE:10210303 WHEEL#:L1 POS.#:4



NJT WHEEL TEMPERATURE DATA

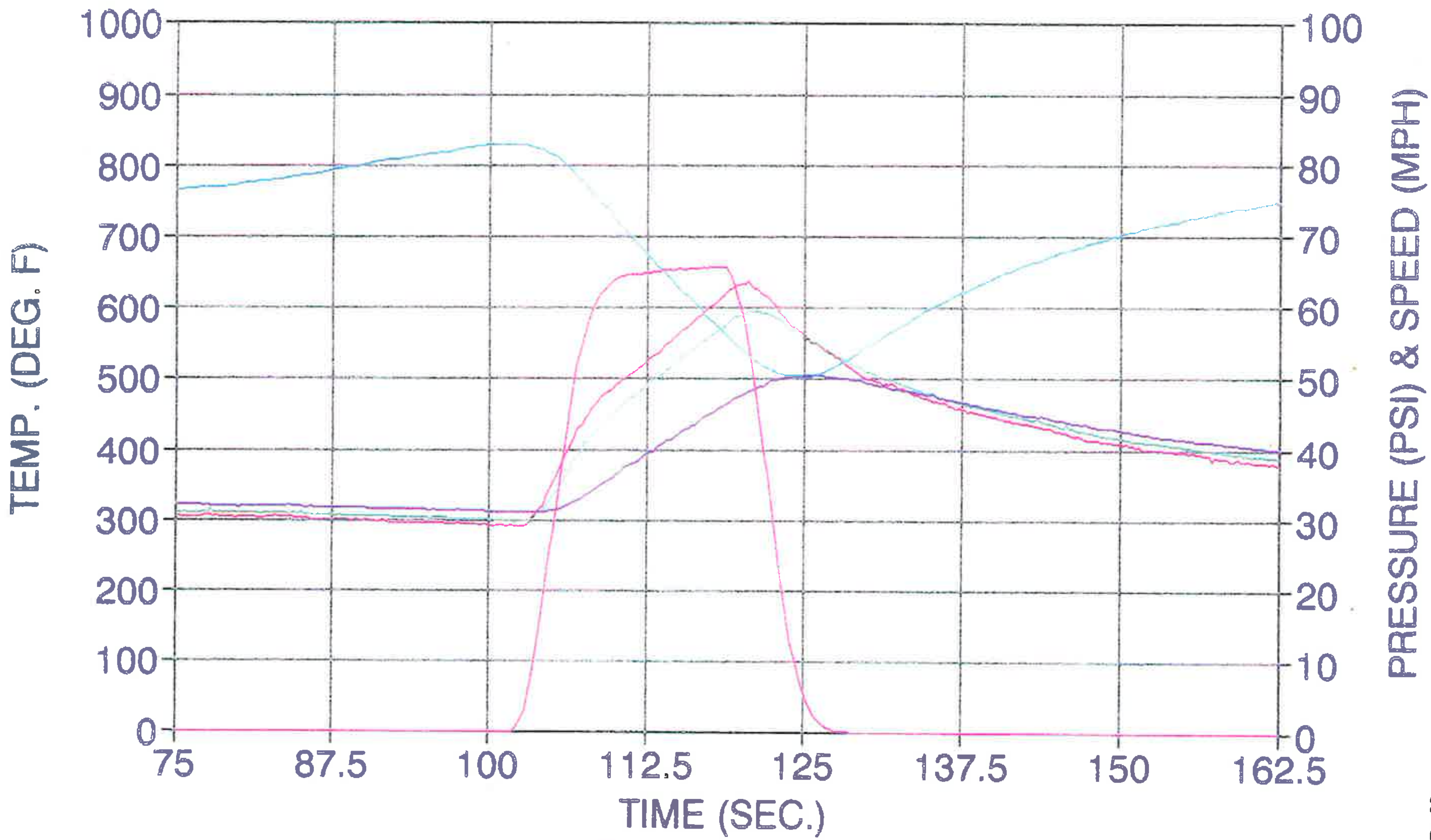
FILE:10210303 WHEEL#:L2 POS.#:6




NJT WHEEL TEMPERATURE DATA
FILE:10210303 WHEEL#:L2 POS.#:7
PRESSURE (PSI) & SPEED (MPH)
TEMP. (DEG. F)
TIME (SEC.)
0 50 100 150 200 250 300 350 400 450 500
0 100 200 300 400 500 600 700 800 900 1000
0 10 20 30 40 50 60 70 80 90 100
KEY: TC-0.1" TC-0.3" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

FILE:10210314 WHEEL#: L1 POS.#: 4

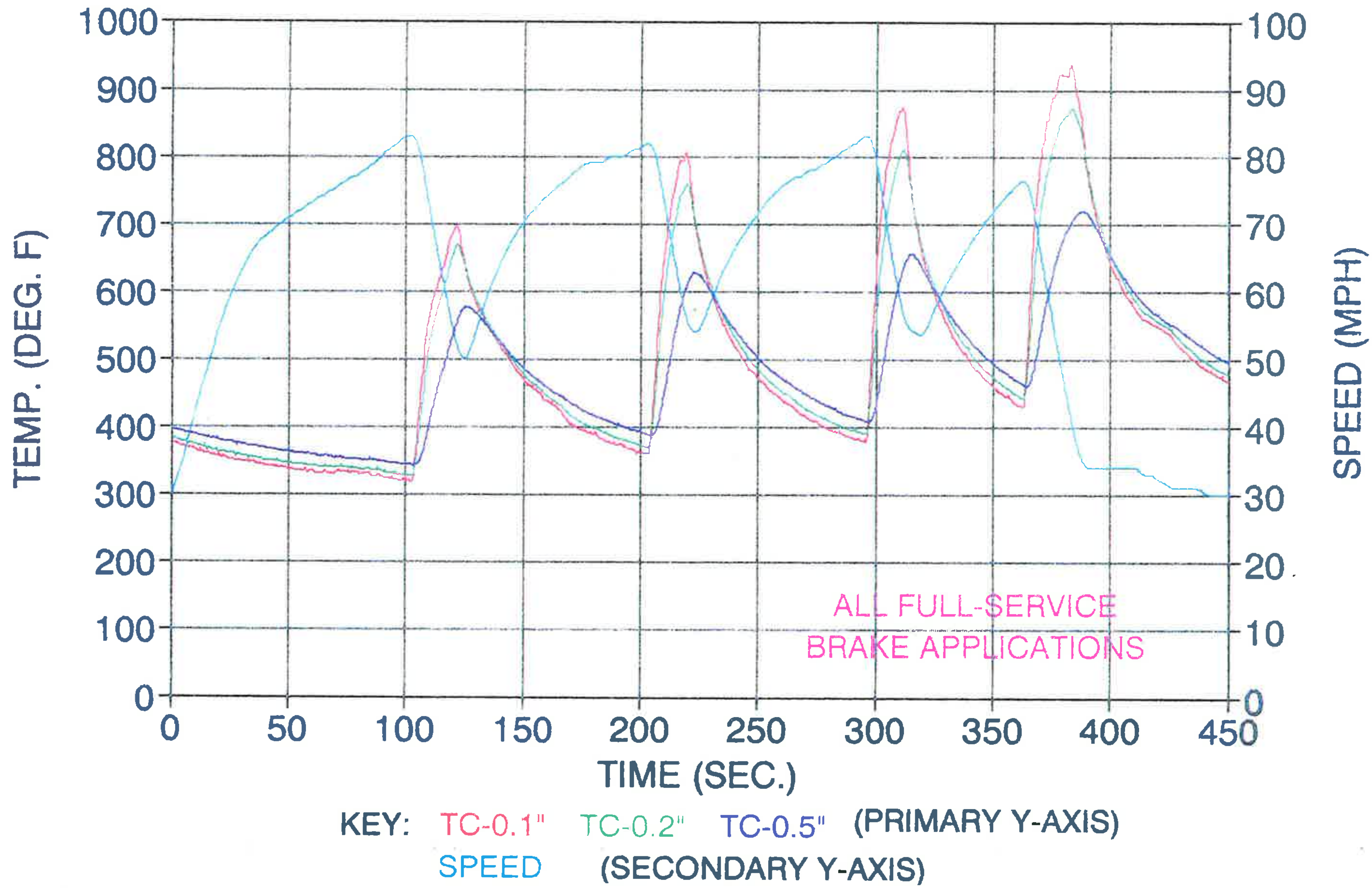


KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)

B.C.P. SPEED (SECONDARY Y-AXIS)

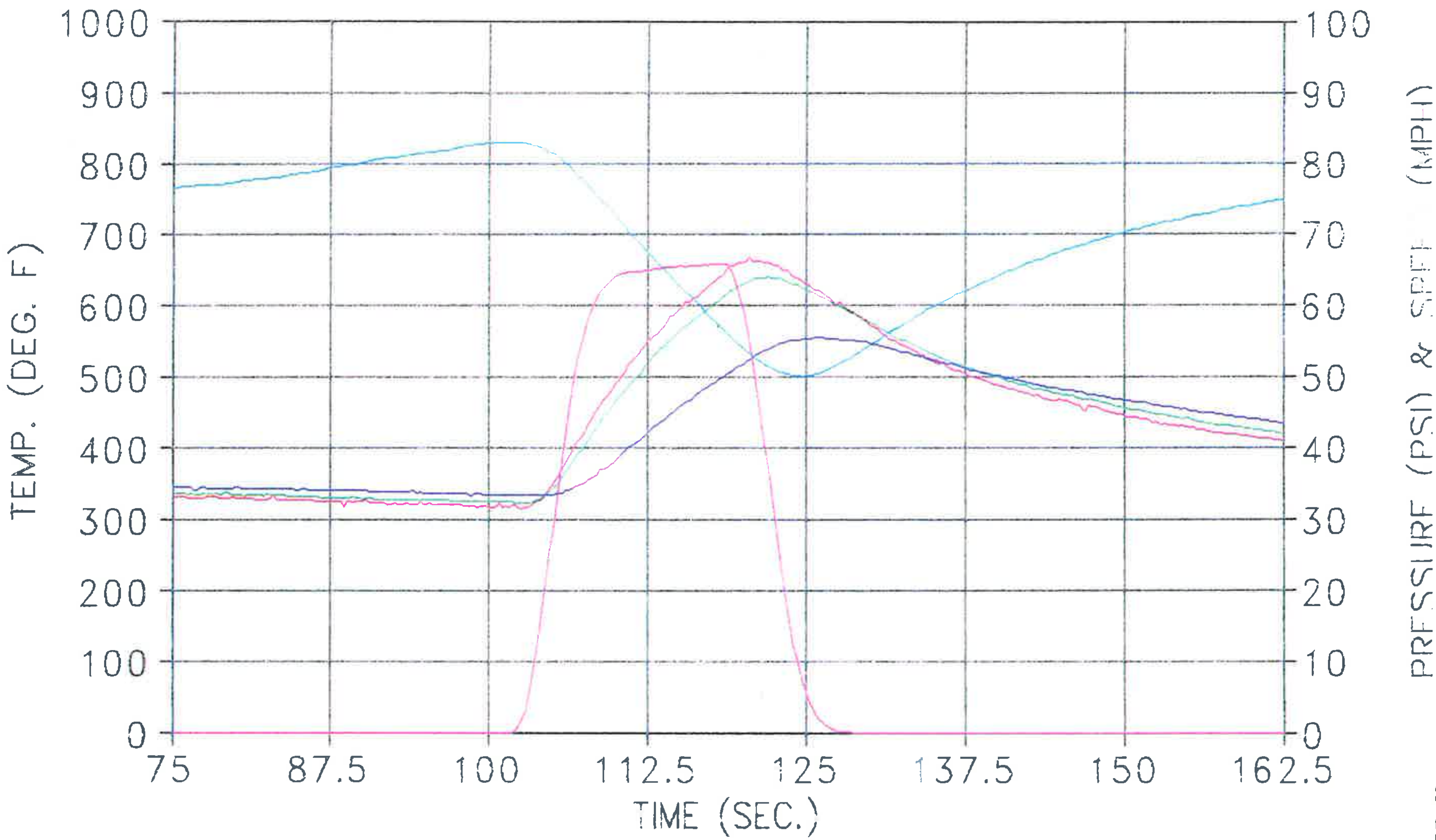
NJT WHEEL TEMPERATURE DATA

FILE:10210314 WHEEL#: L2 POS.#: 6



NJT WHEEL TEMPERATURE DATA

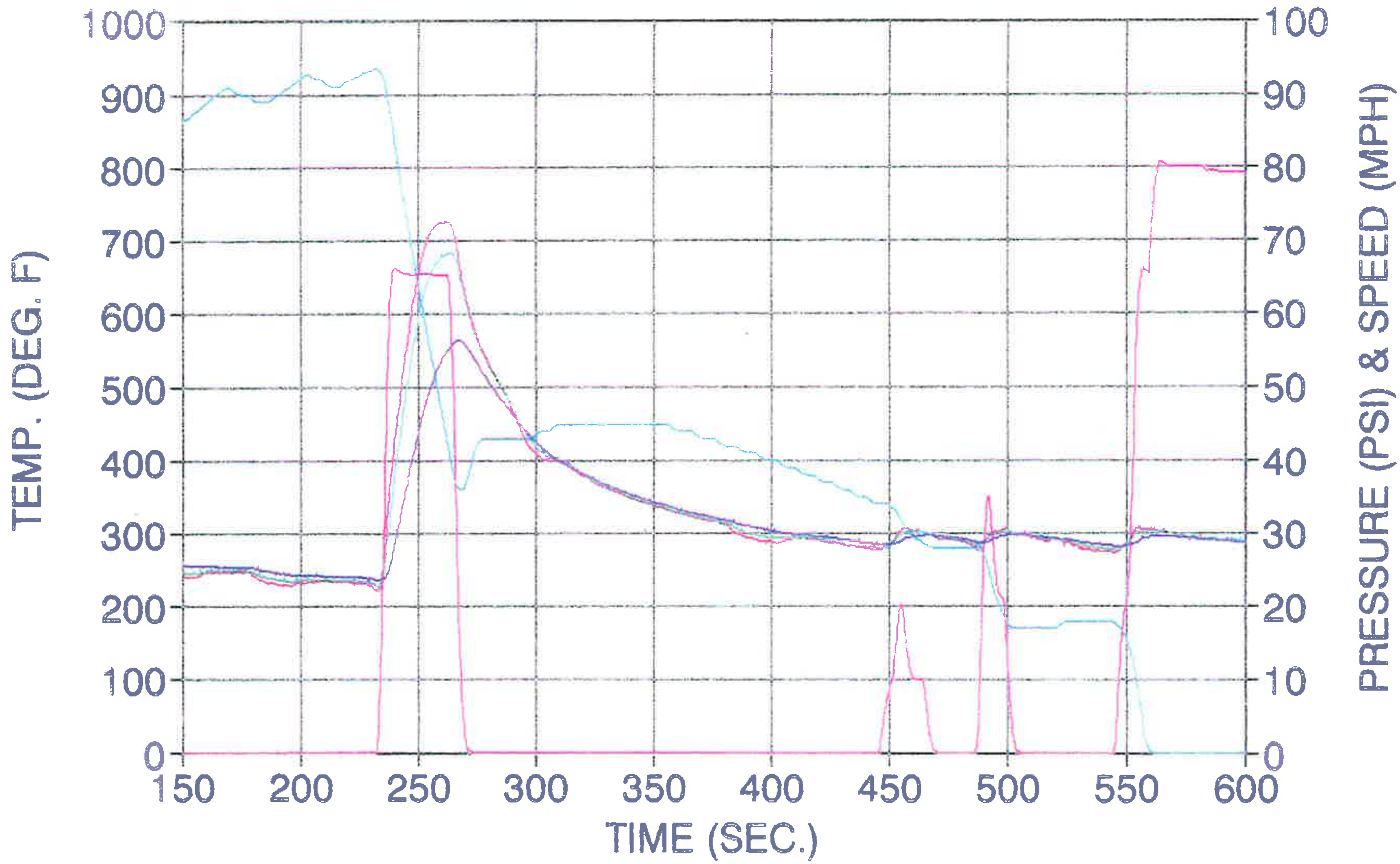
FILE:10210314 WHEEL#:L2 POS.#:7



KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

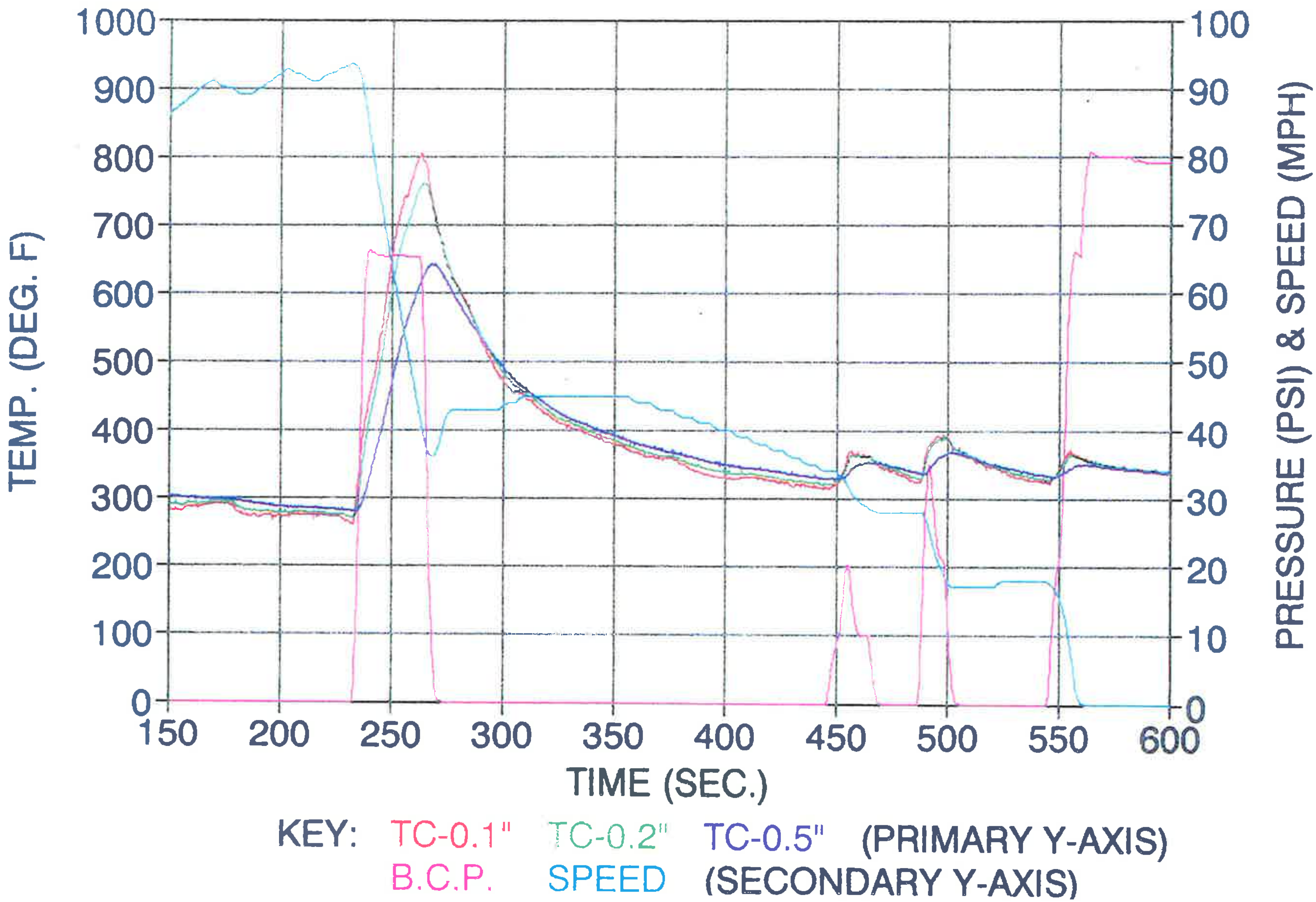
FILE:10210335 WHEEL#:L1 POS.#:4

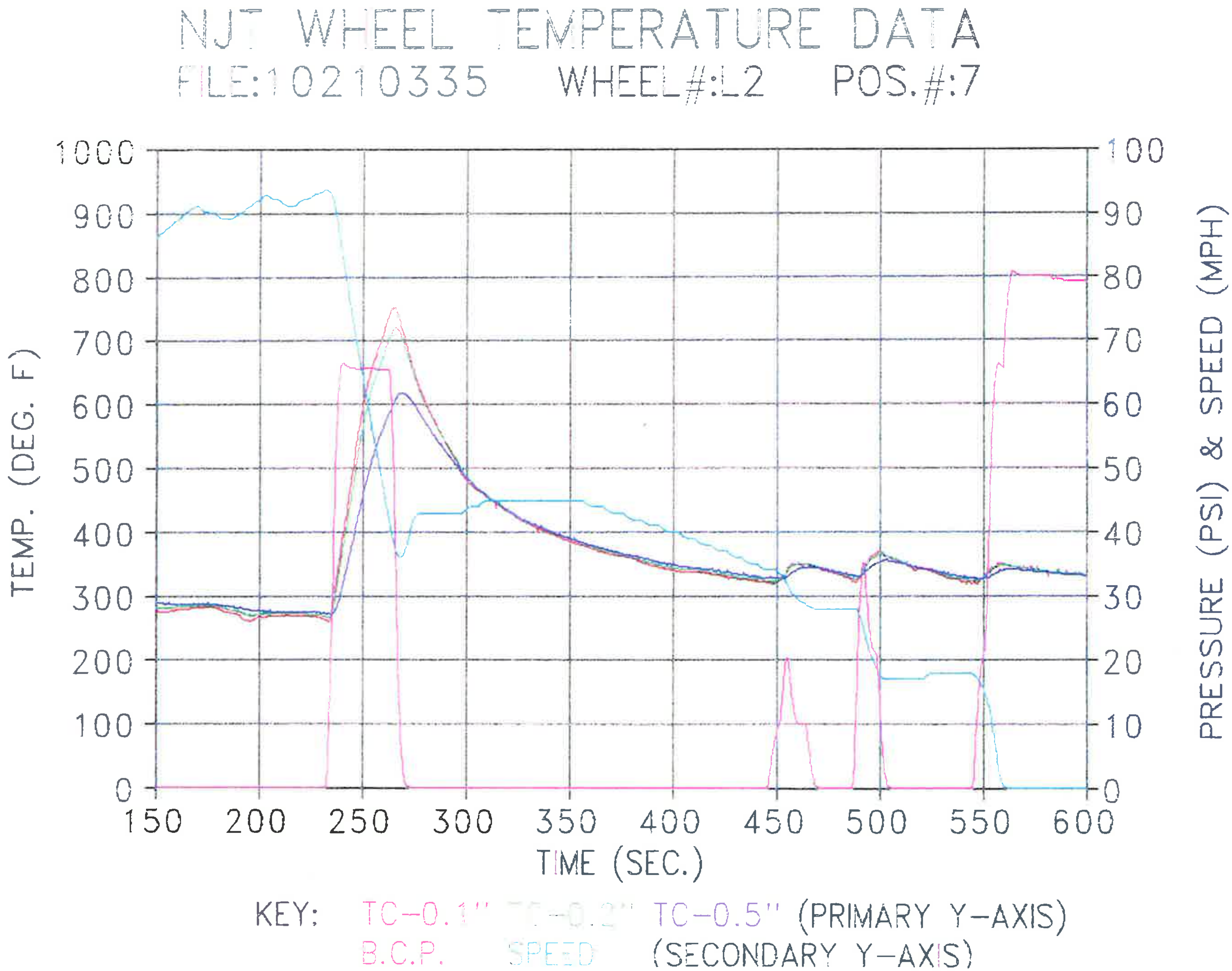


KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

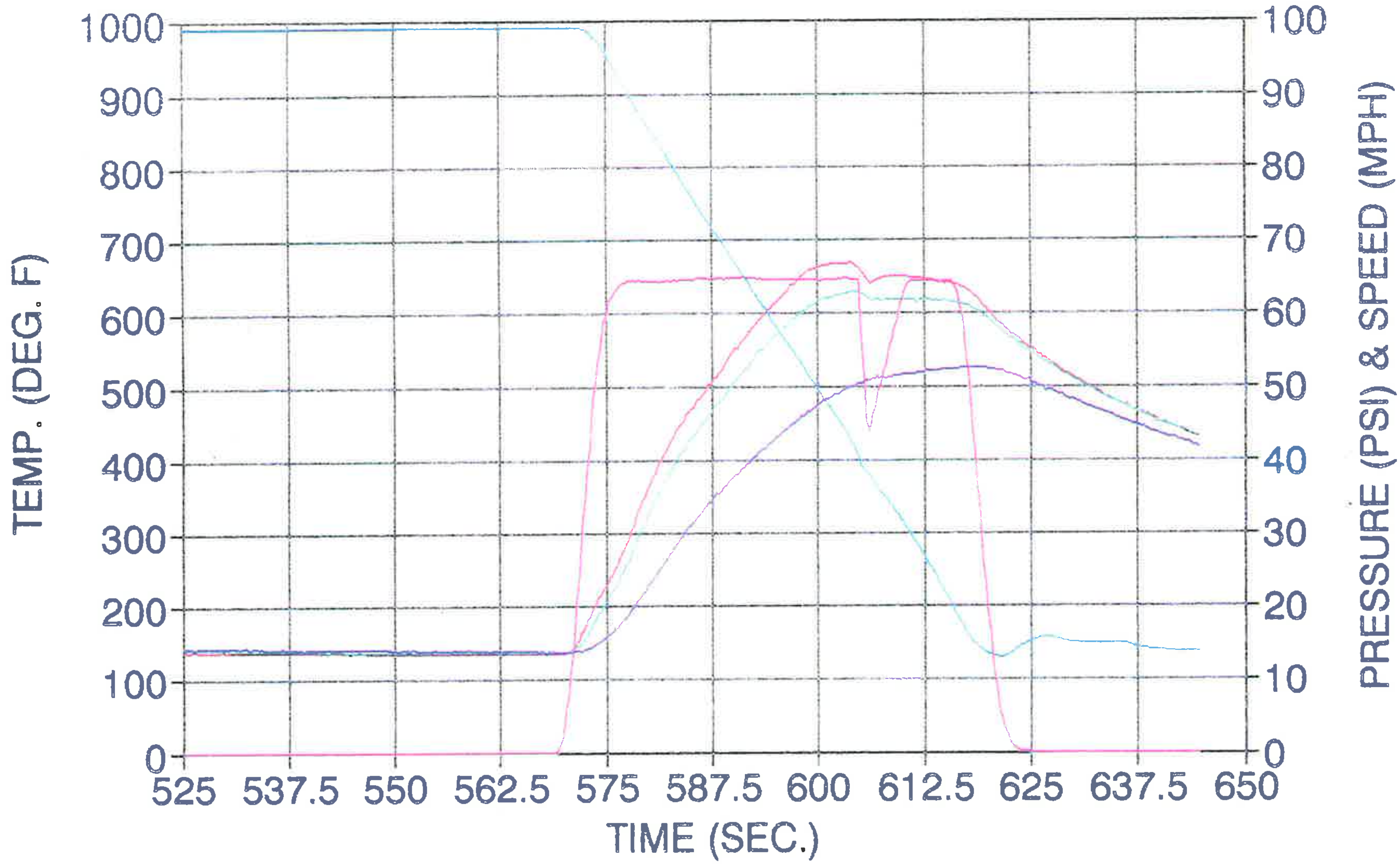
FILE:10210335 WHEEL#:L2 POS.#:6




NJT WHEEL TEMPERATURE DATA
FILE:10210335 WHEEL#:L2 POS.#:7
TEMP. (DEG. F)
PRESSURE (PSI) & SPEED (MPH)
1000
900
800
700
600
500
400
300
200
100
0
100
90
80
70
60
50
40
30
20
10
0
150
200
250
300
350
400
450
500
550
600
TIME (SEC.)
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

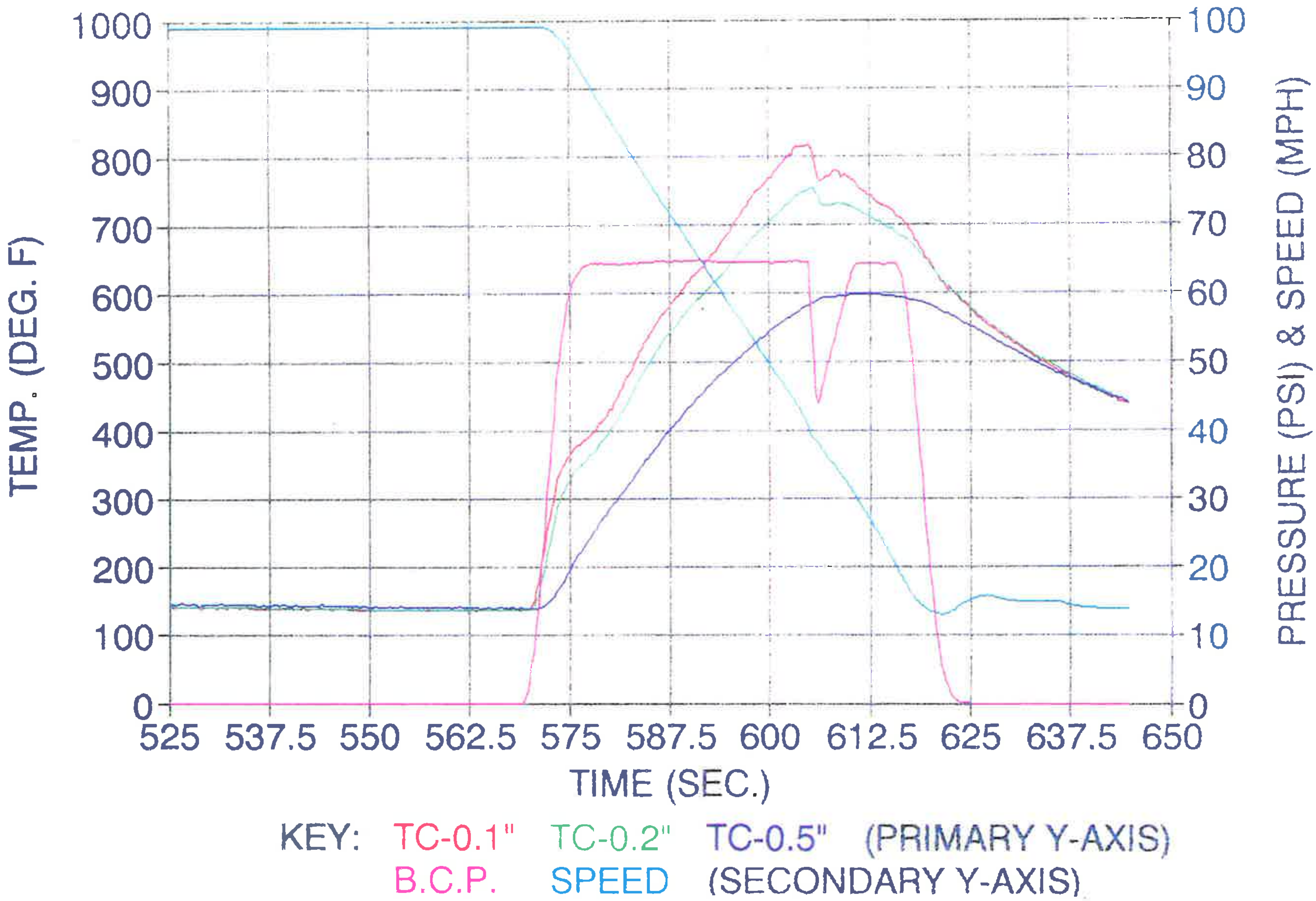
FILE:10220003 WHEEL#:L1 POS.#:4

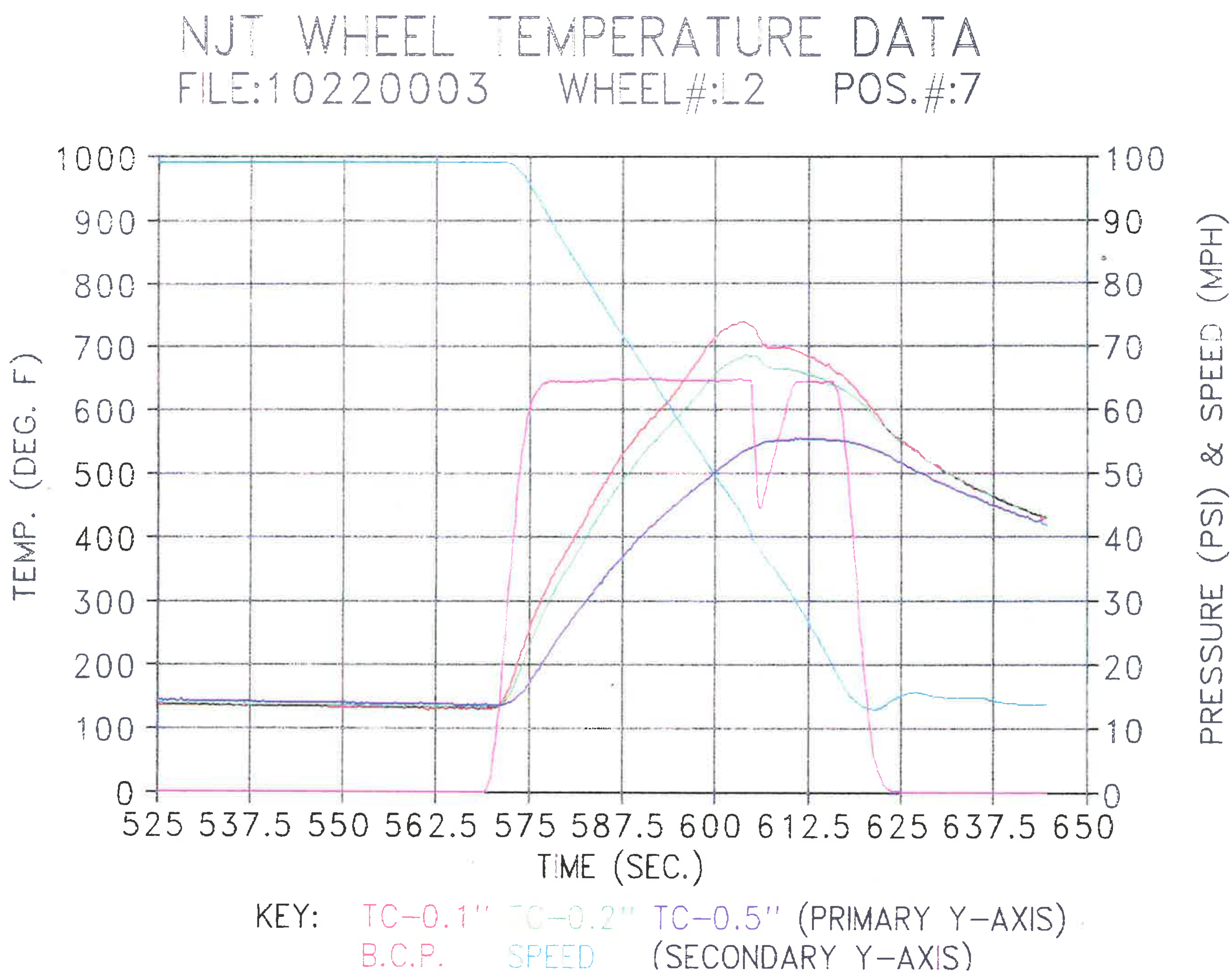


KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

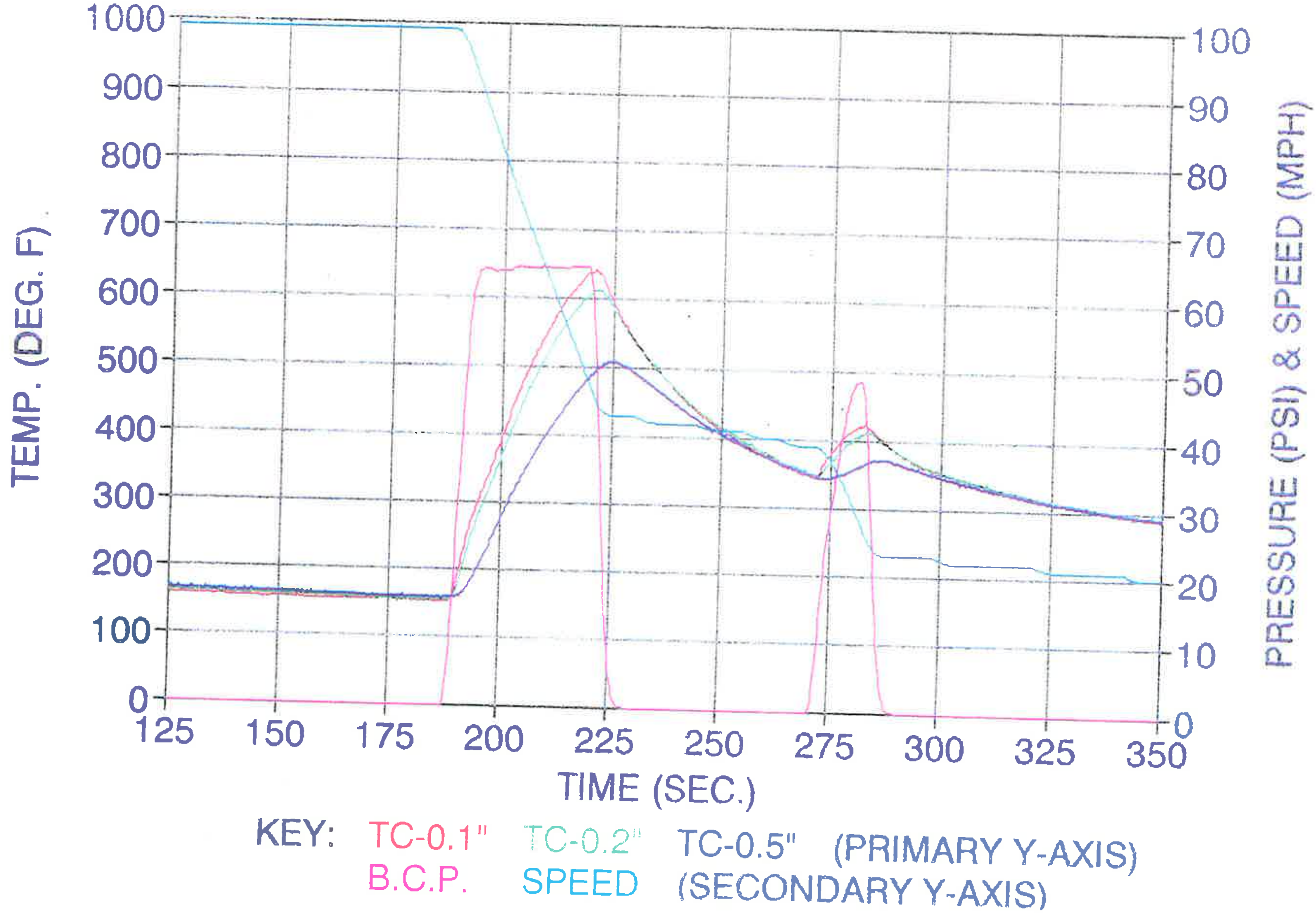
FILE:10220003 WHEEL#:L2 POS.#:6




NJT WHEEL TEMPERATURE DATA
FILE:10220003 WHEEL#:L2 POS.#:7
TEMP. (DEG. F)
0
100
200
300
400
500
600
700
800
900
1000
PRESSURE (PSI) & SPEED (MPH)
0
10
20
30
40
50
60
70
80
90
100
525 537.5 550 562.5 575 587.5 600 612.5 625 637.5 650
TIME (SEC.)
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

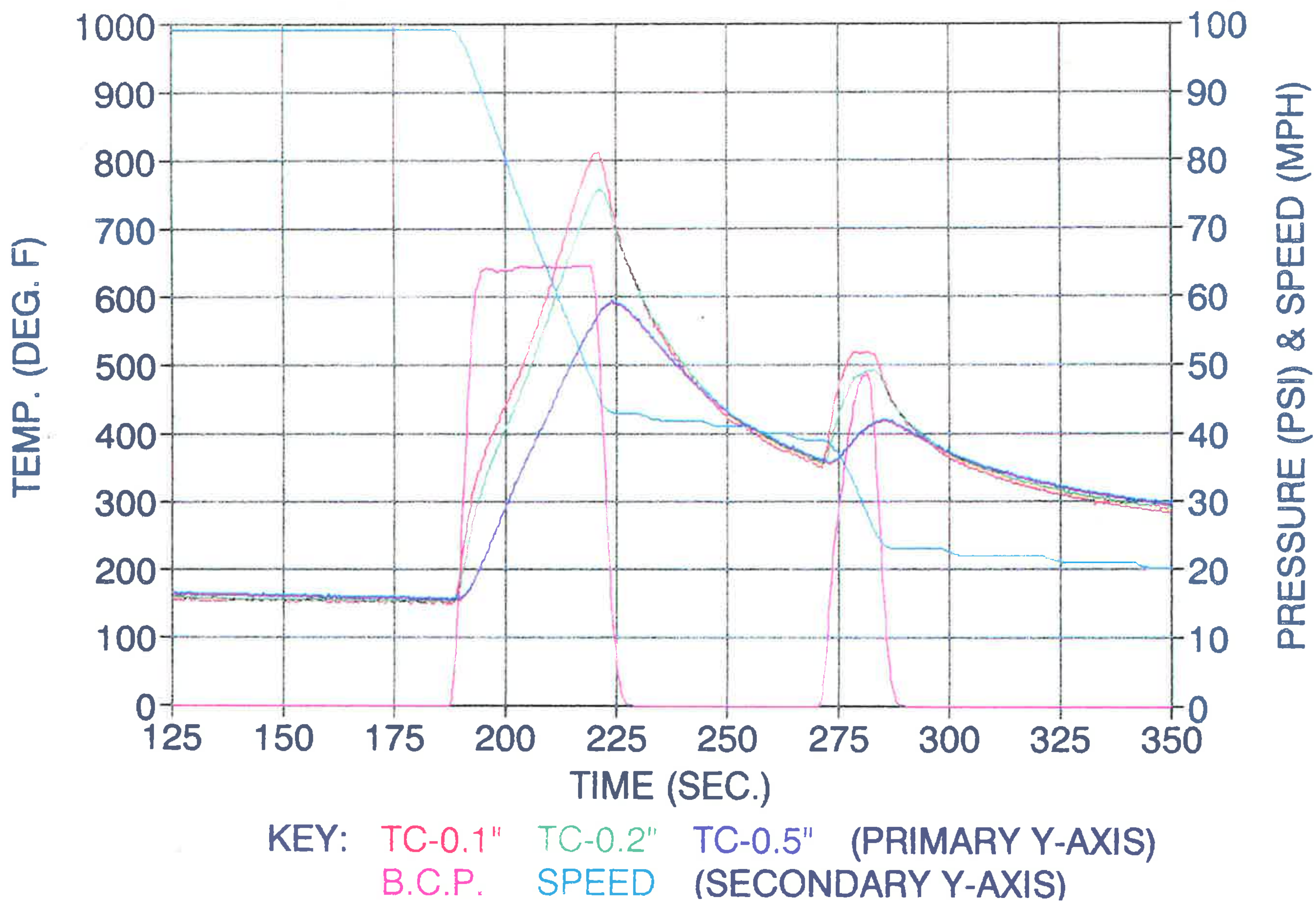
NJT WHEEL TEMPERATURE DATA

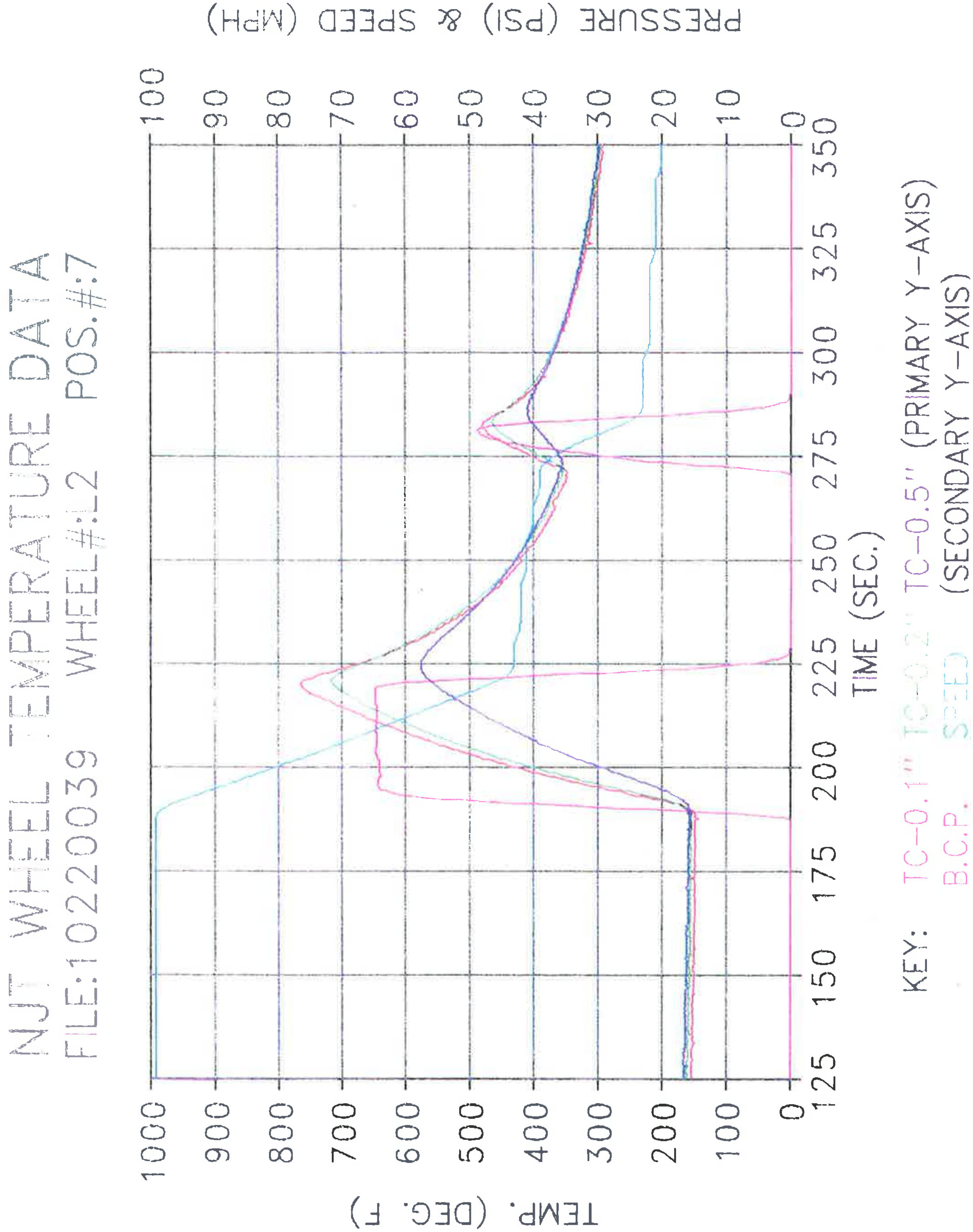
FILE:10220039 WHEEL#:L1 POS.#:4



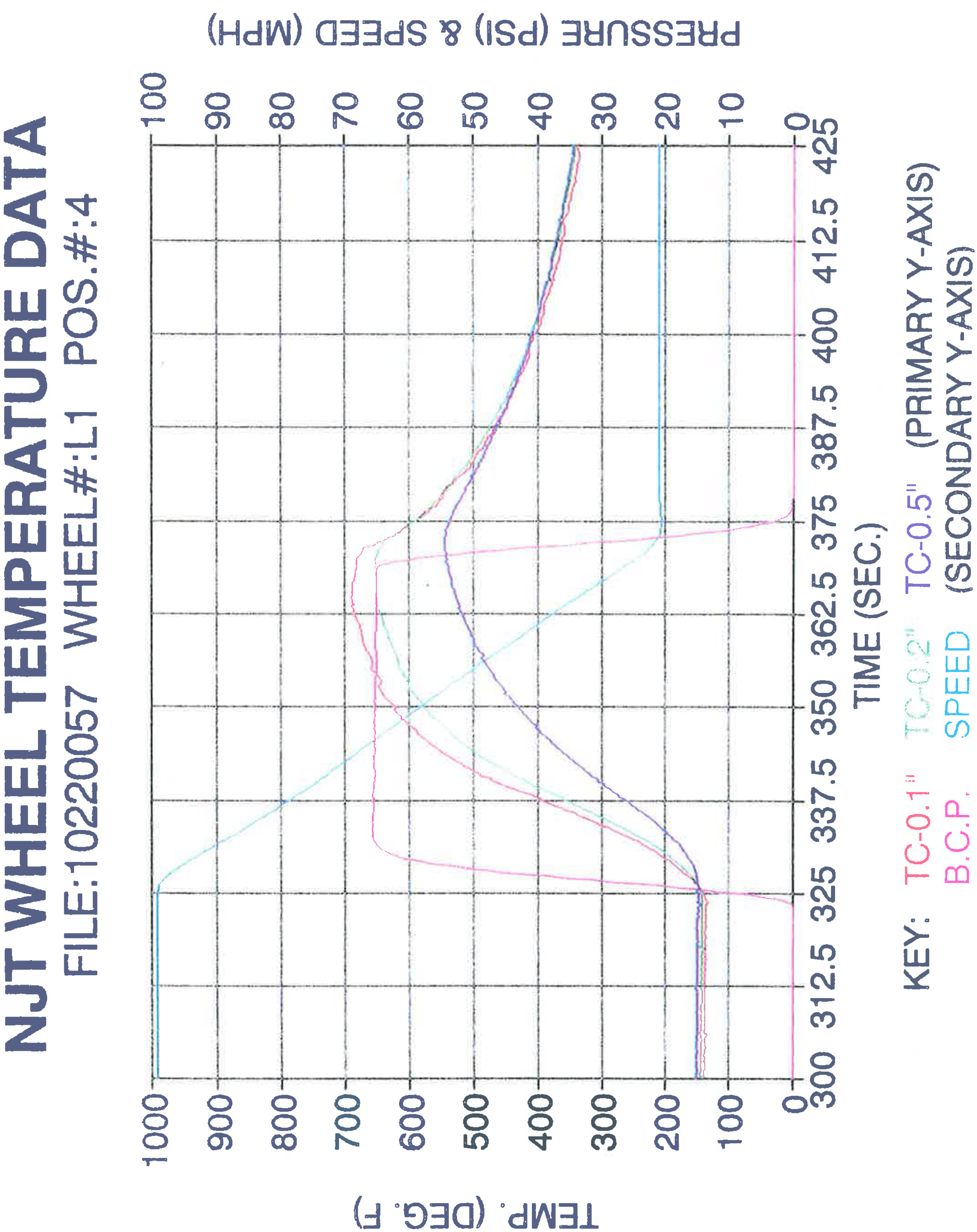
NJT WHEEL TEMPERATURE DATA

FILE:10220039 WHEEL#:L2 POS.#:6



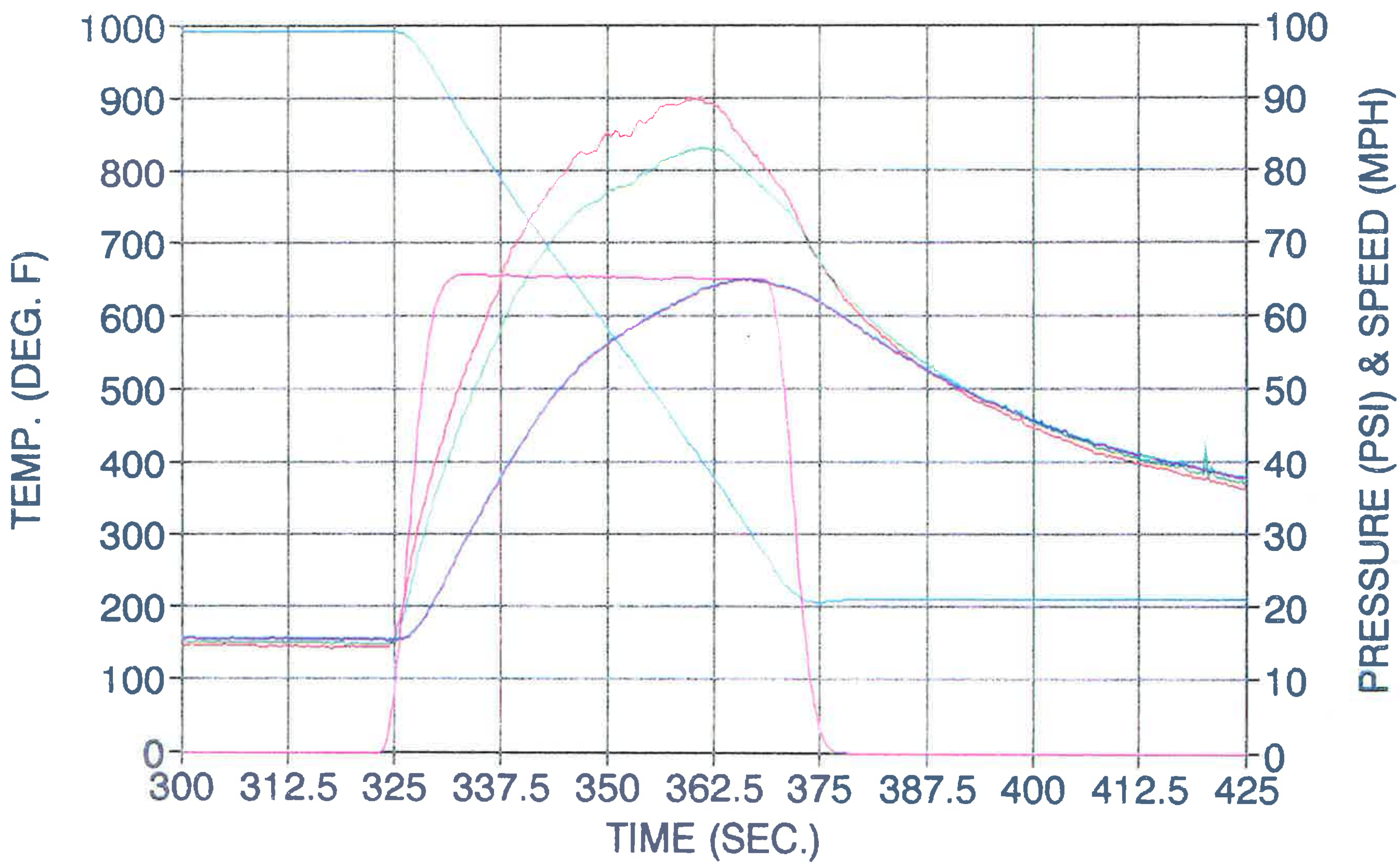


NJT WHEEL TEMPERATURE DATA
FILE:10220039 WHEEL#:L2 POS.#:7
TEMP. (DEG. F)
1000
900
800
700
600
500
400
300
200
100
0
PRESSURE (PSI) & SPEED (MPH)
100
90
80
70
60
50
40
30
20
10
0
125
150
175
200
225
250
275
300
325
350
TIME (SEC.)
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

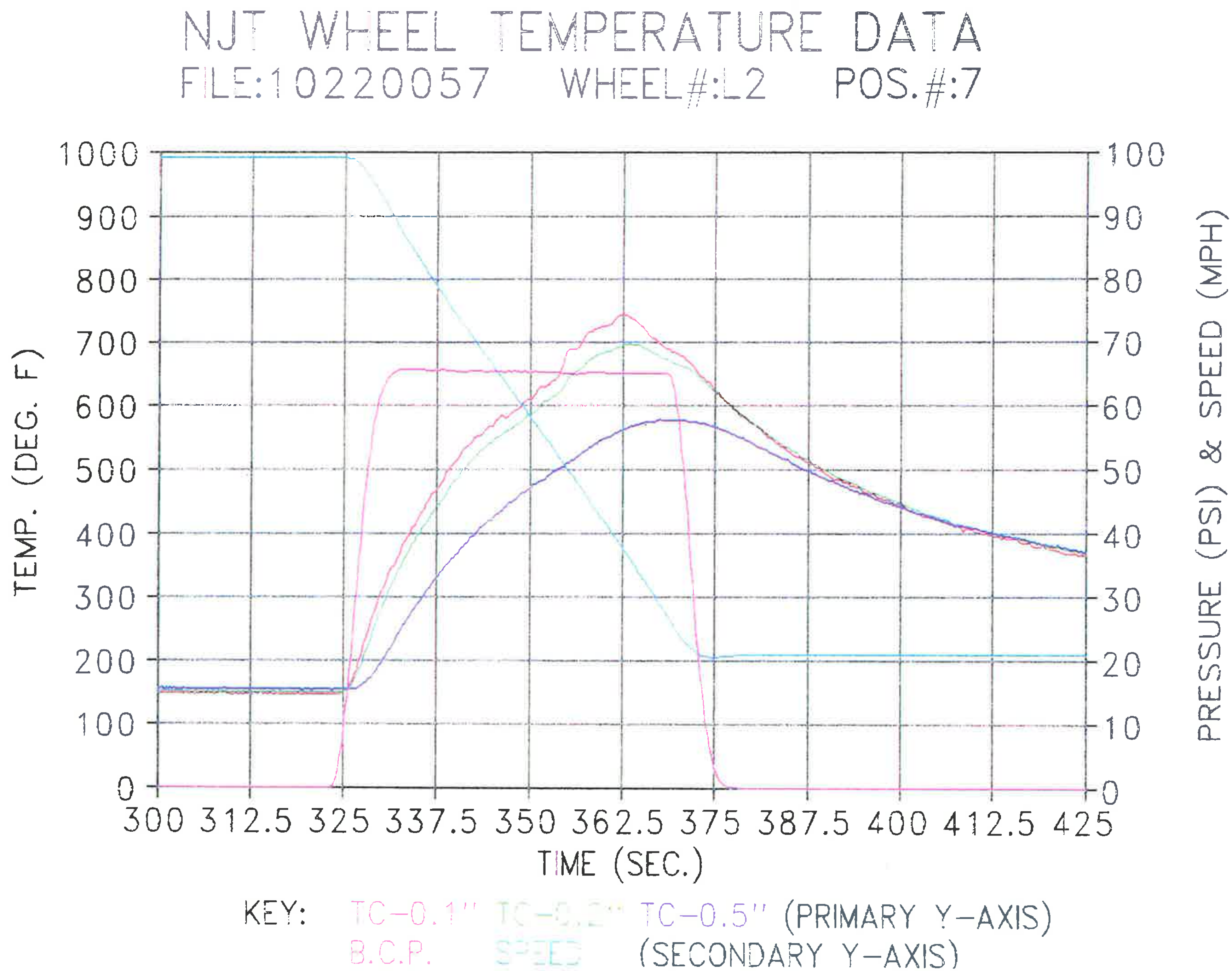

NJT WHEEL TEMPERATURE DATA
FILE:102220057 WHEEL#:L1 POS.#:4
PRESSURE (PSI) & SPEED (MPH)
TEMP. (DEG. F)
TIME (SEC.)
0 10 20 30 40 50 60 70 80 90 100
0 100 200 300 400 500 600 700 800 900 1000
300 312.5 325 337.5 350 362.5 375 387.5 400 412.5 425
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

FILE:10220057 WHEEL#:L21 POS.#:6



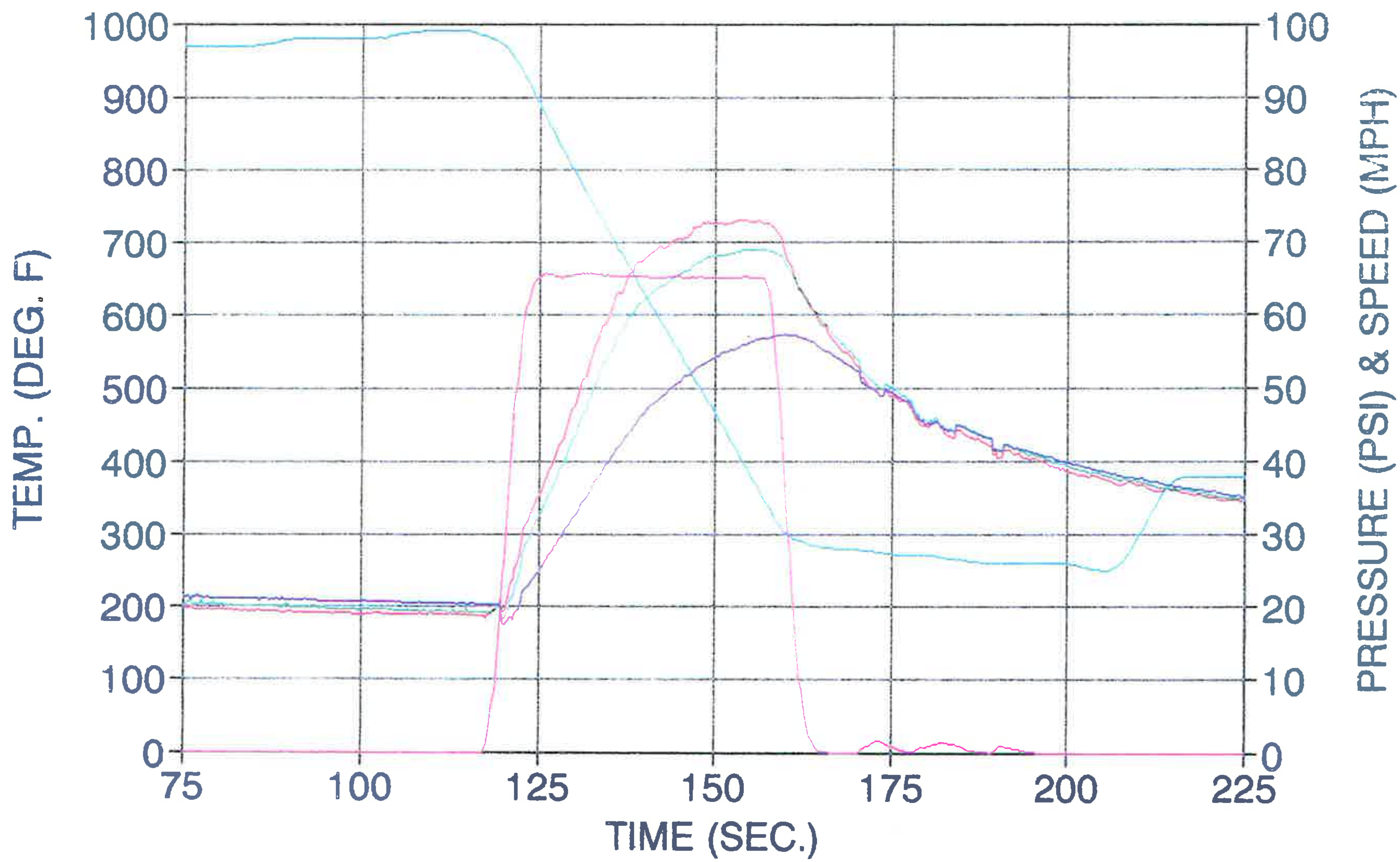
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)



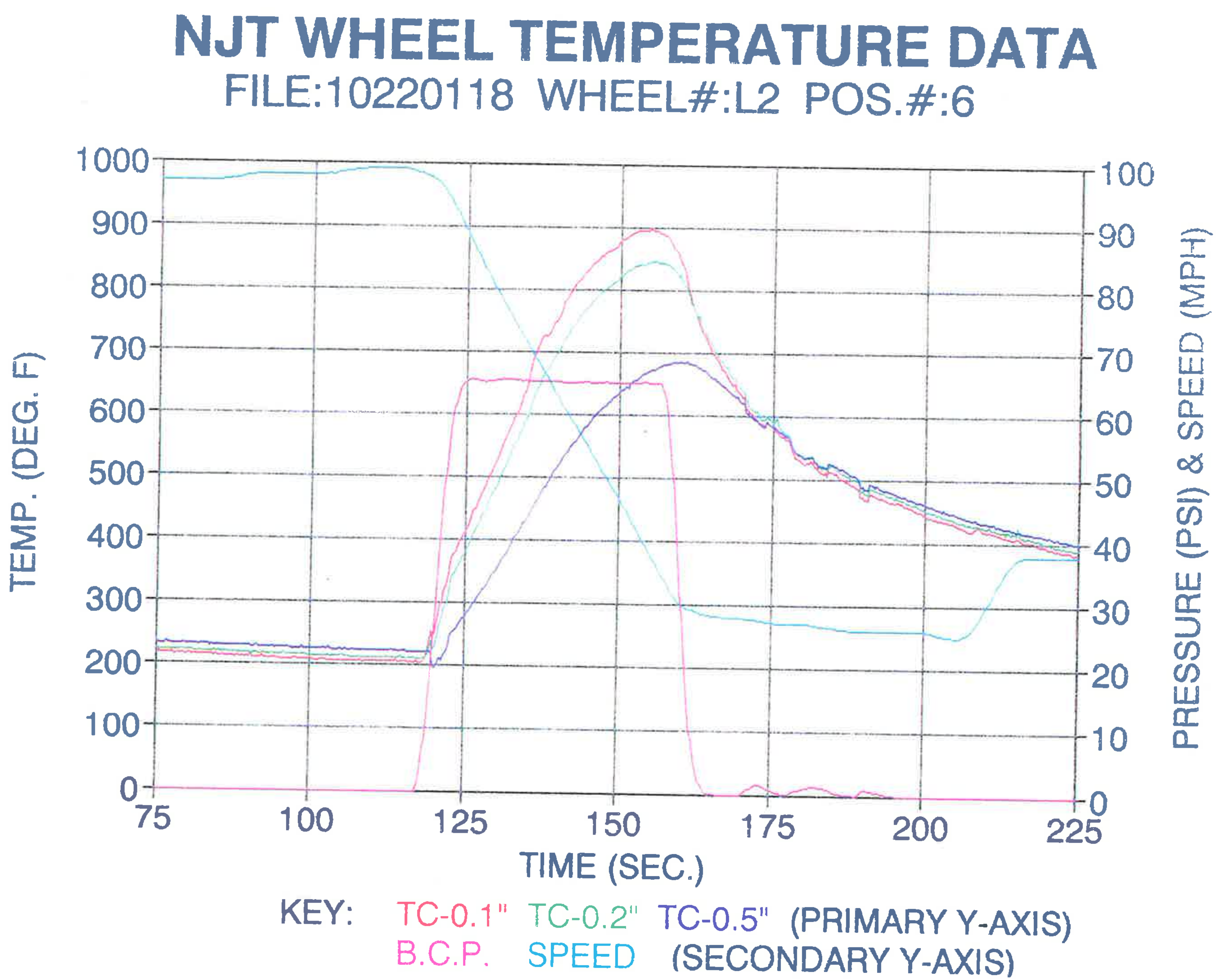
NJT WHEEL TEMPERATURE DATA
FILE:10220057 WHEEL#:L2 POS.#:7
TEMP. (DEG. F)
1000
900
800
700
600
500
400
300
200
100
0
PRESSURE (PSI) & SPEED (MPH)
100
90
80
70
60
50
40
30
20
10
0
300 312.5 325 337.5 350 362.5 375 387.5 400 412.5 425
TIME (SEC.)
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

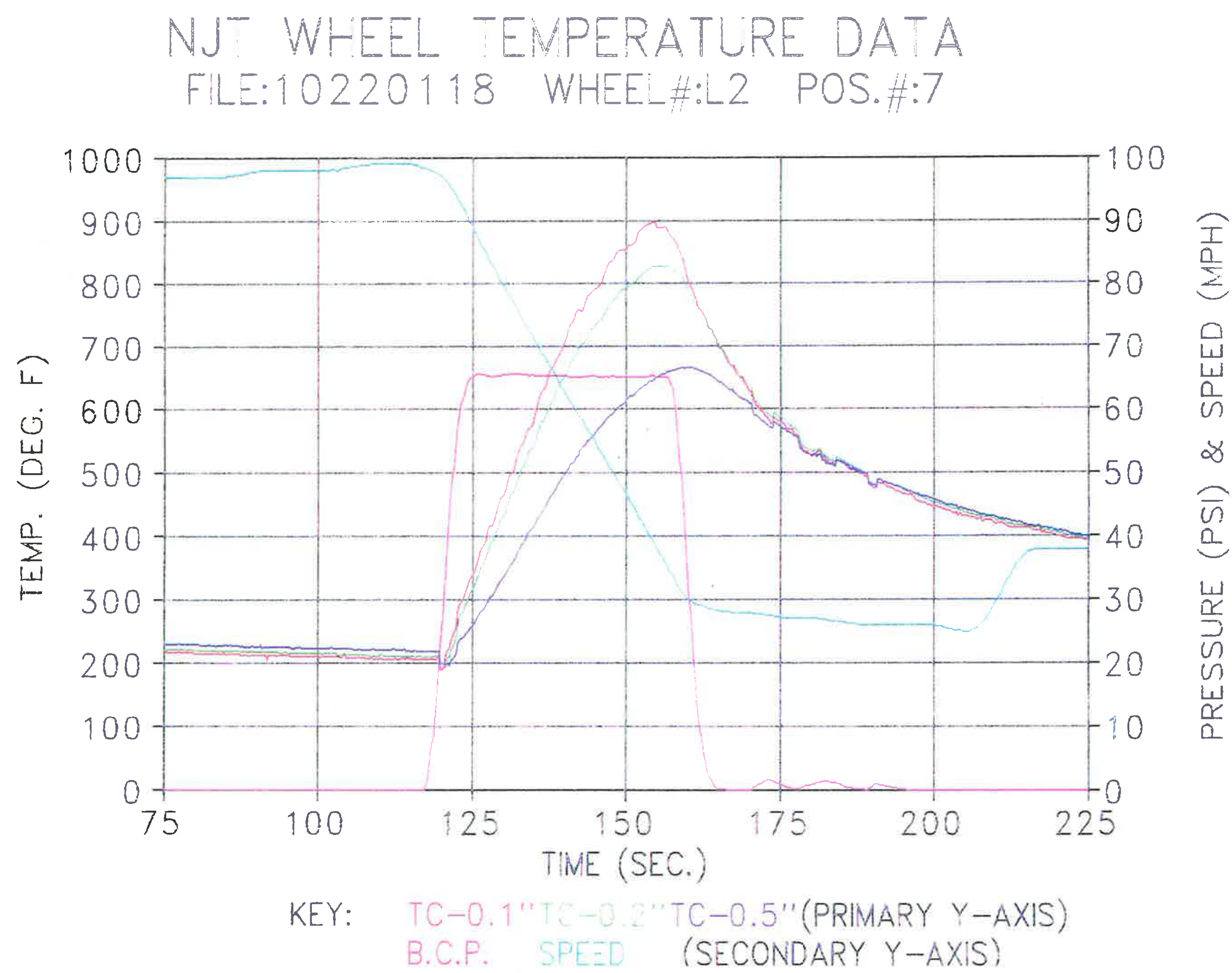
NJT WHEEL TEMPERATURE DATA

FILE:10220118 WHEEL#:L1 POS.#:4



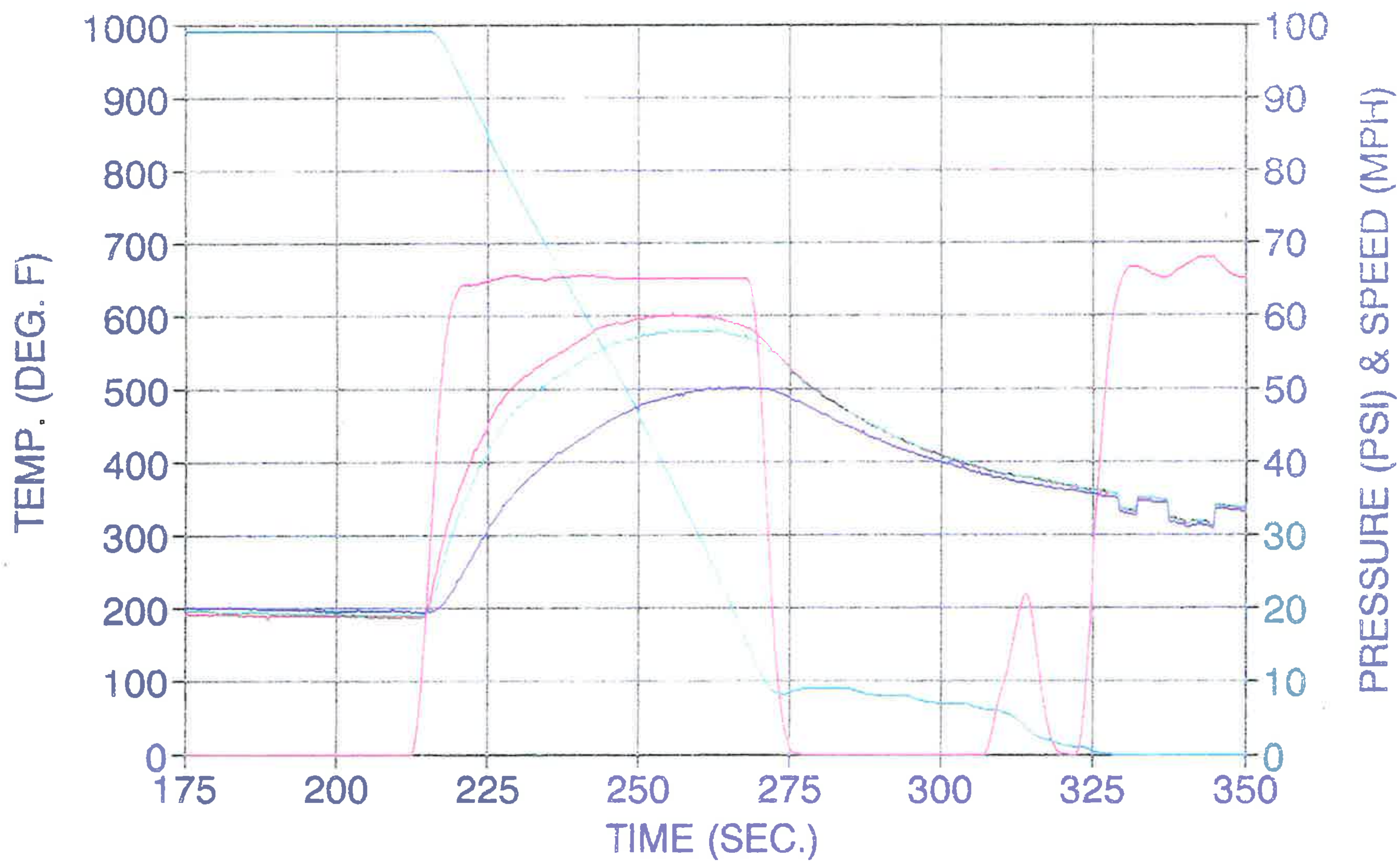
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)


NJT WHEEL TEMPERATURE DATA
FILE:10220118 WHEEL#:L2 POS.#:6
TEMP. (DEG. F)
1000
900
800
700
600
500
400
300
200
100
0
PRESSURE (PSI) & SPEED (MPH)
100
90
80
70
60
50
40
30
20
10
0
75
100
125
150
175
200
225
TIME (SEC.)
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

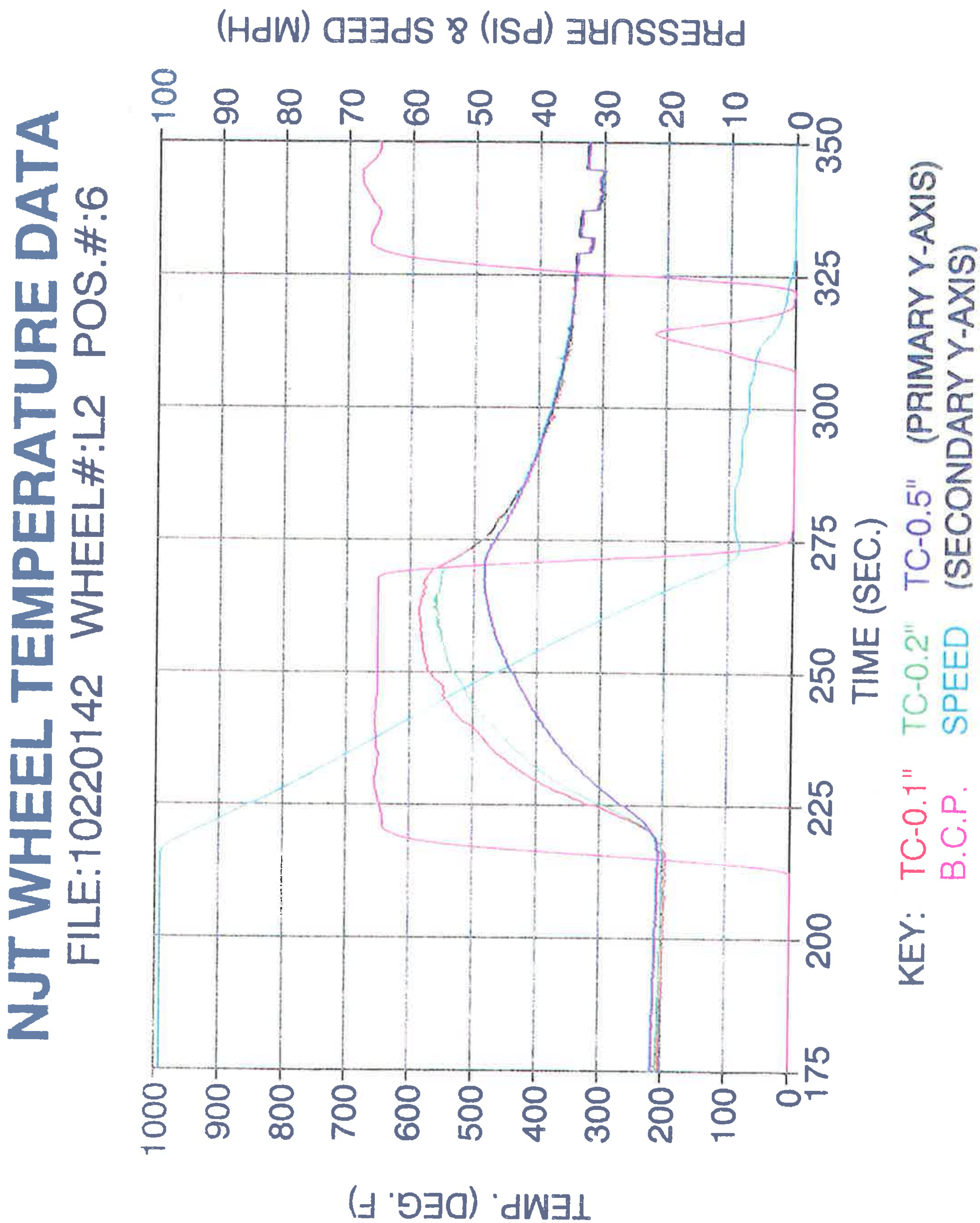

NJT WHEEL TEMPERATURE DATA
FILE:10220118 WHEEL#:L2 POS.#:7
TEMP. (DEG. F)
0
100
200
300
400
500
600
700
800
900
1000
PRESSURE (PSI) & SPEED (MPH)
0
10
20
30
40
50
60
70
80
90
100
75
100
125
150
175
200
225
TIME (SEC.)
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

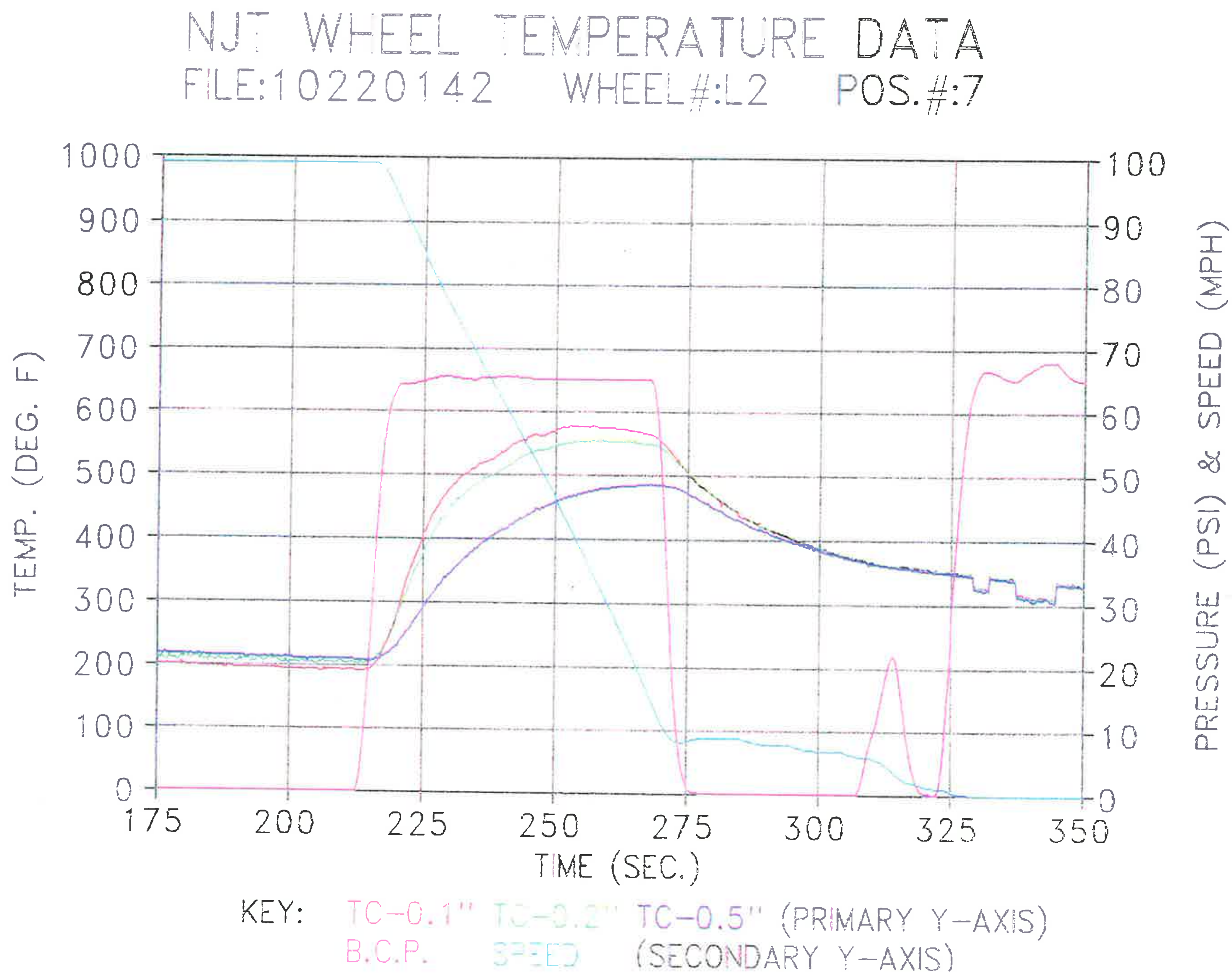
NJT WHEEL TEMPERATURE DATA

FILE:10220142 WHEEL#:L1 POS.#:4



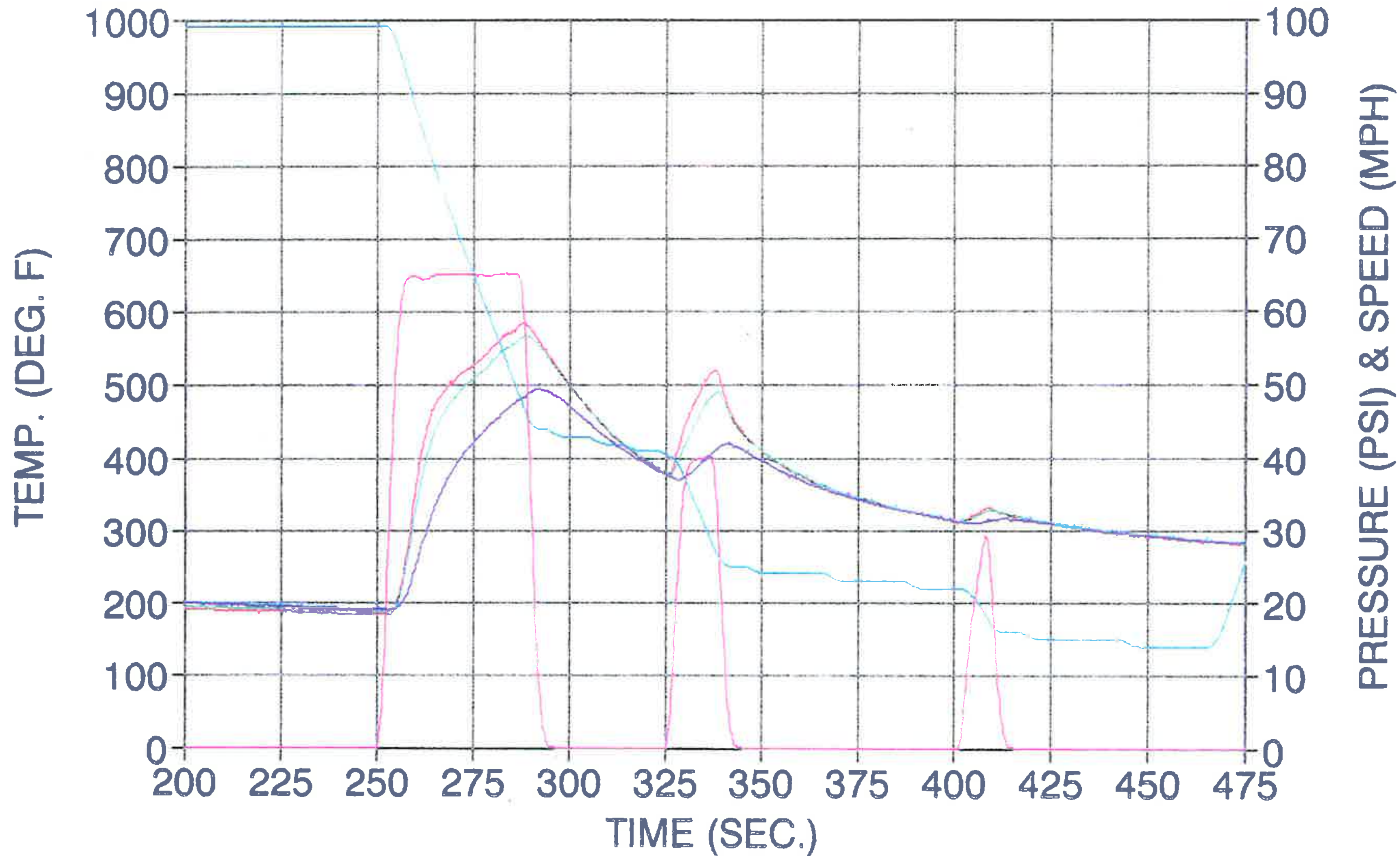
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)


NJT WHEEL TEMPERATURE DATA
FILE:10220142 WHEEL#:L2 POS.#:6
PRESSURE (PSI) & SPEED (MPH)
100
90
80
70
60
50
40
30
20
10
0
TEMP. (DEG. F)
1000
900
800
700
600
500
400
300
200
100
0
175
200
225
250
275
300
325
350
TIME (SEC.)
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)


NJT WHEEL TEMPERATURE DATA
FILE:10220142 WHEEL#:L2 POS.#:7
TEMP. (DEG. F)
PRESSURE (PSI) & SPEED (MPH)
TIME (SEC.)
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

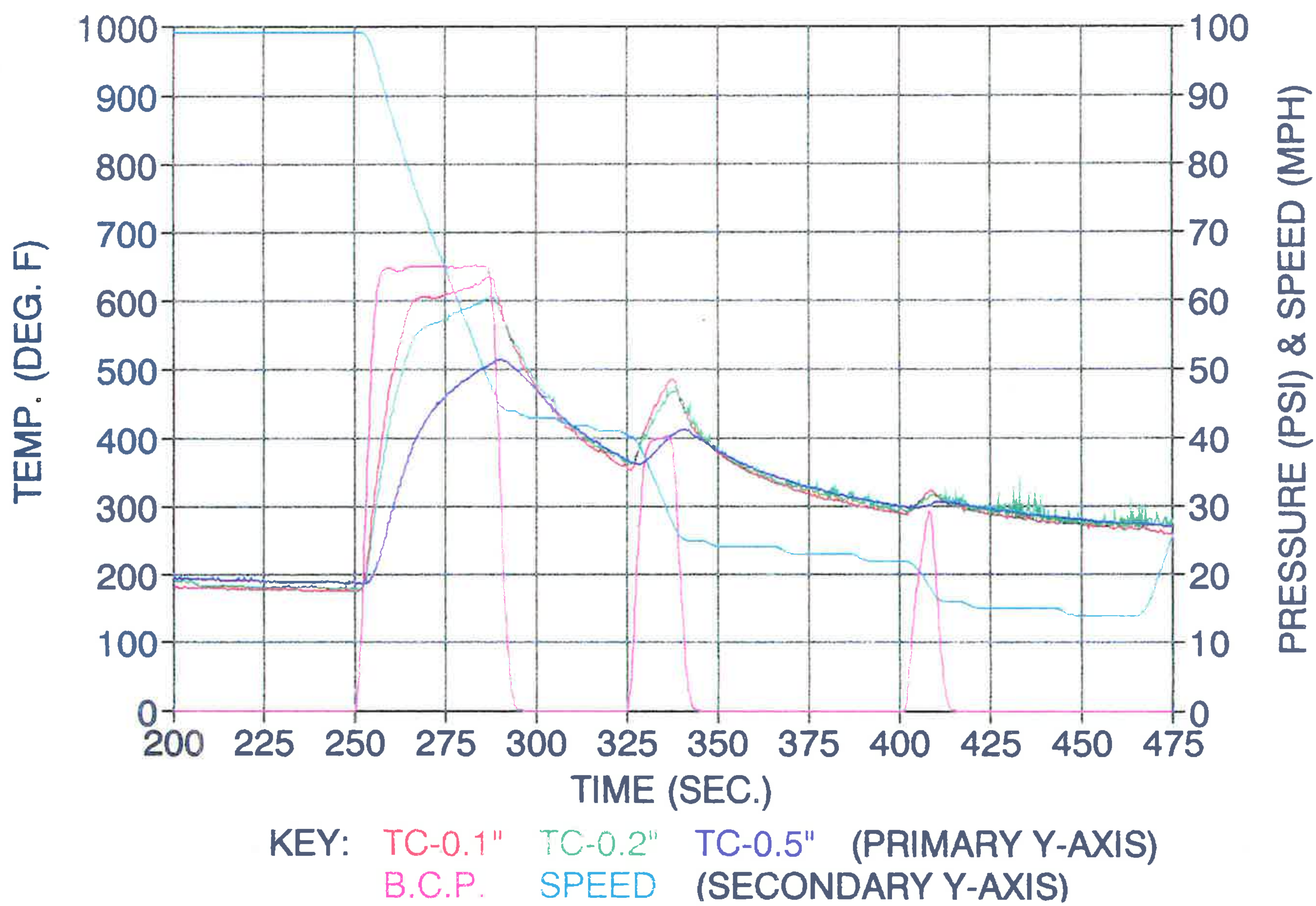
FILE:10220201 WHEEL#:L1 POS.#:4

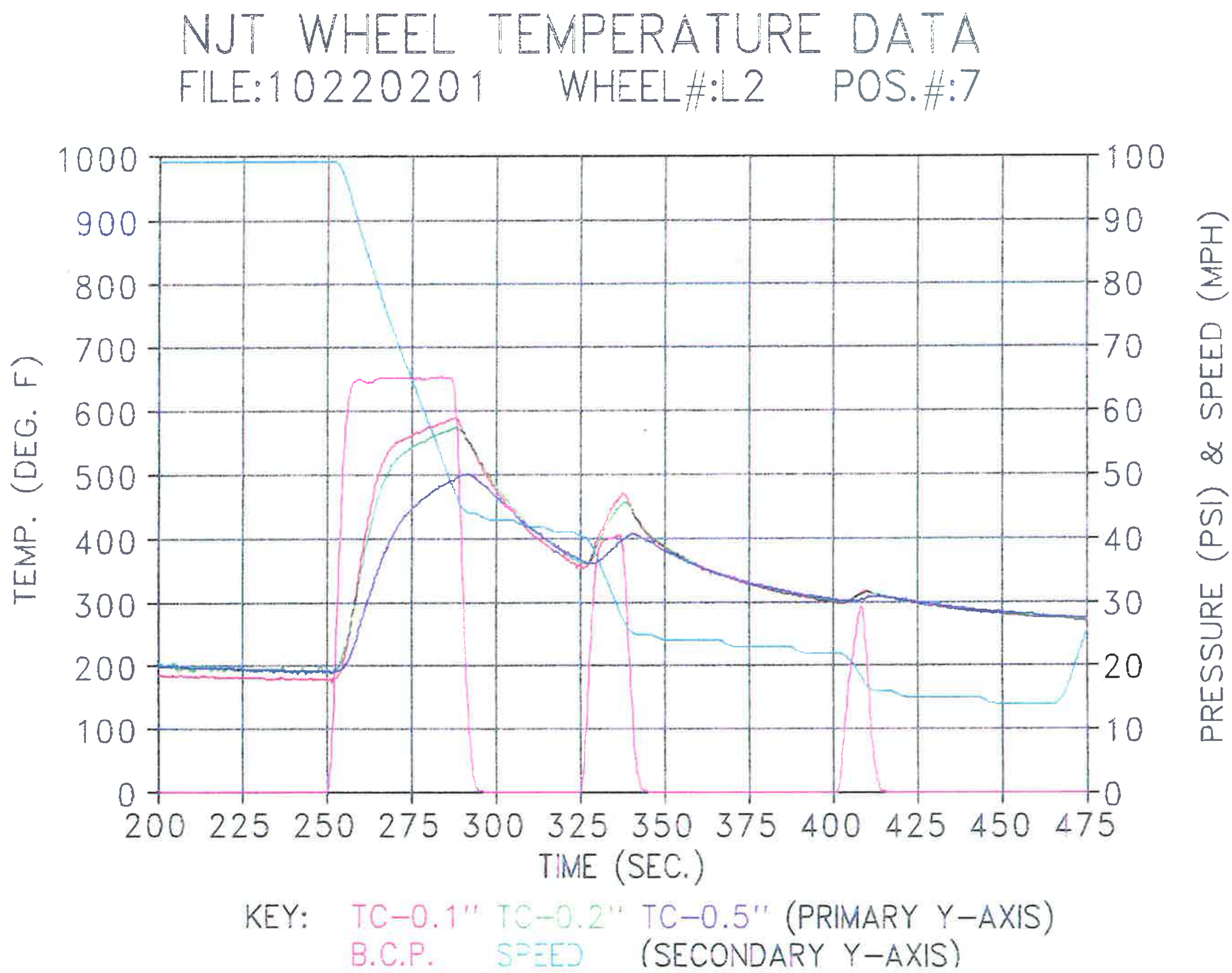


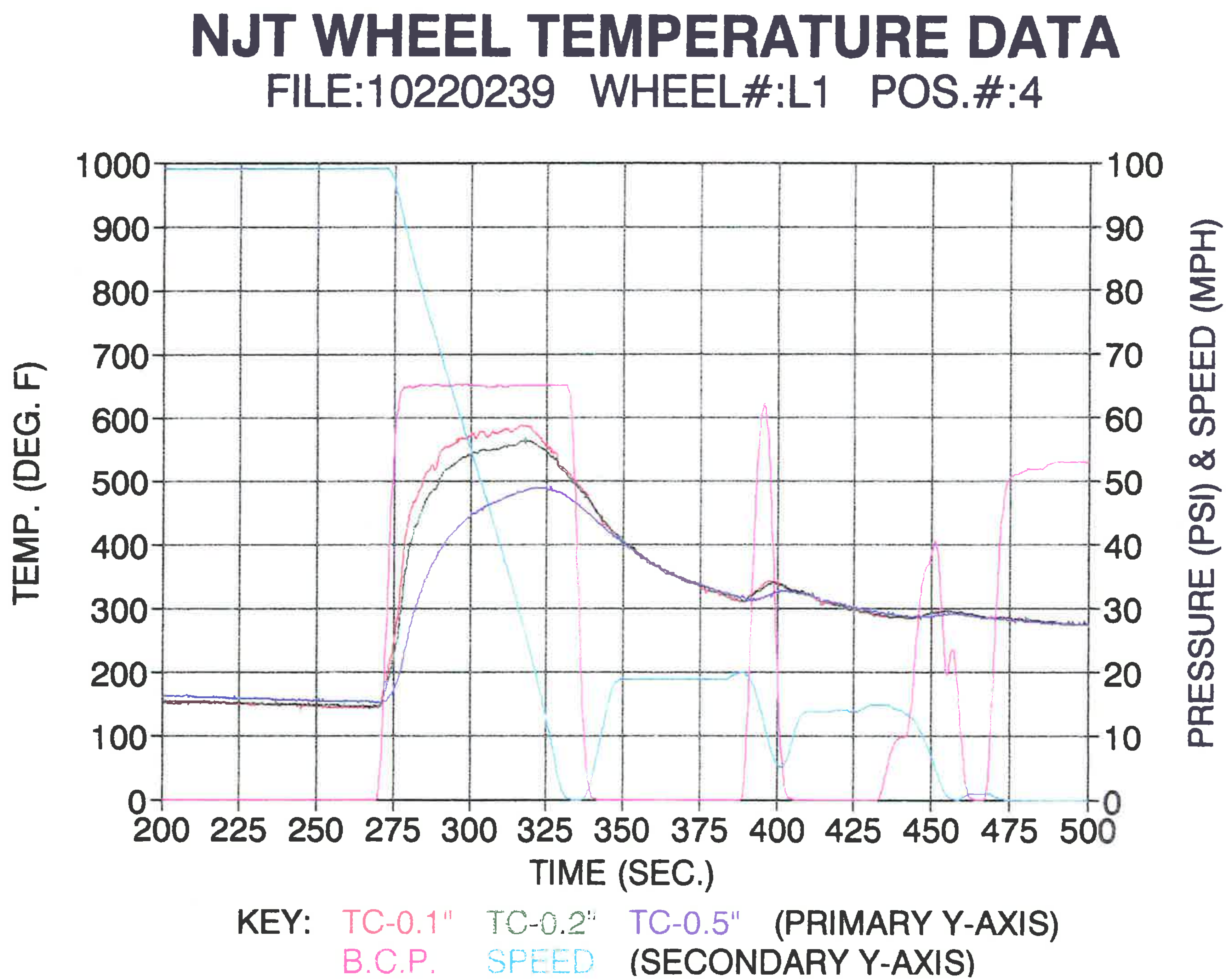
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

FILE:10220201 WHEEL#:L2 POS.#:6

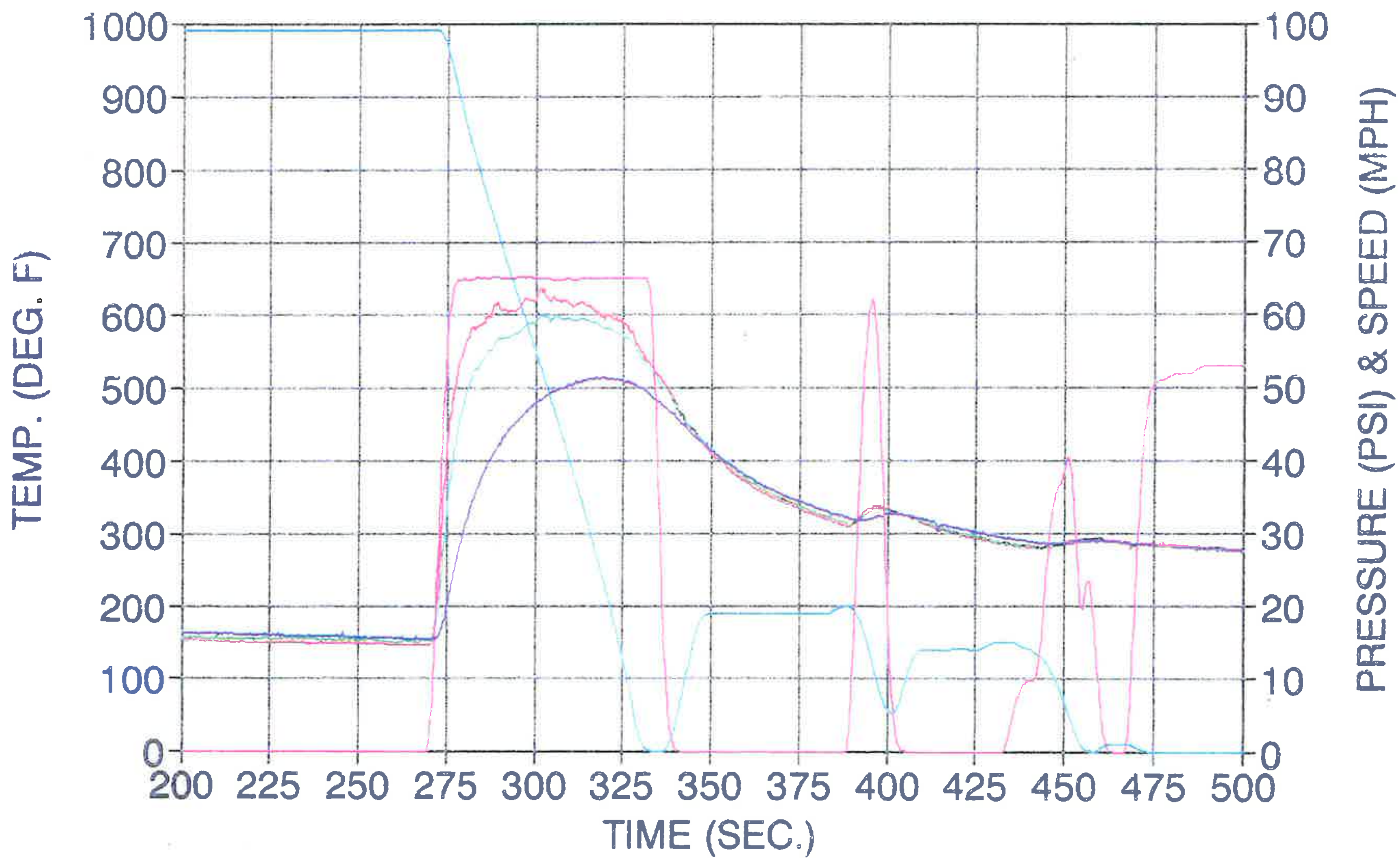



NJT WHEEL TEMPERATURE DATA
FILE:10220201 WHEEL#:L2 POS.#:7
TEMP. (DEG. F)
0
100
200
300
400
500
600
700
800
900
1000
PRESSURE (PSI) & SPEED (MPH)
0
10
20
30
40
50
60
70
80
90
100
200 225 250 275 300 325 350 375 400 425 450 475
TIME (SEC.)
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)


NJT WHEEL TEMPERATURE DATA
FILE:10220239 WHEEL#:L1 POS.#:4
TEMP. (DEG. F)
1000
900
800
700
600
500
400
300
200
100
0
PRESSURE (PSI) & SPEED (MPH)
100
90
80
70
60
50
40
30
20
10
0
200 225 250 275 300 325 350 375 400 425 450 475 500
TIME (SEC.)
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

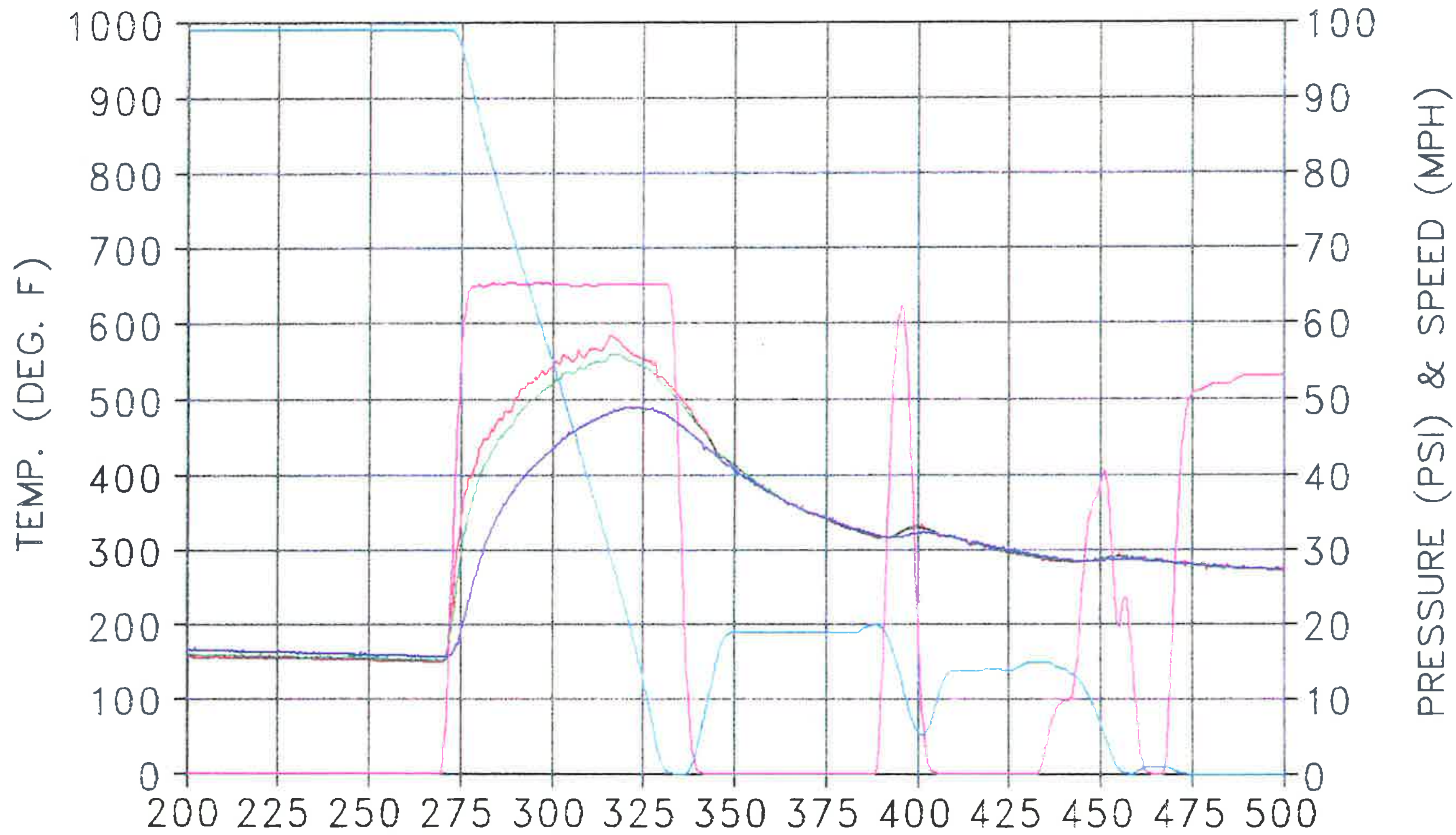
FILE:10220239 WHEEL#:L2 POS.#:6



KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

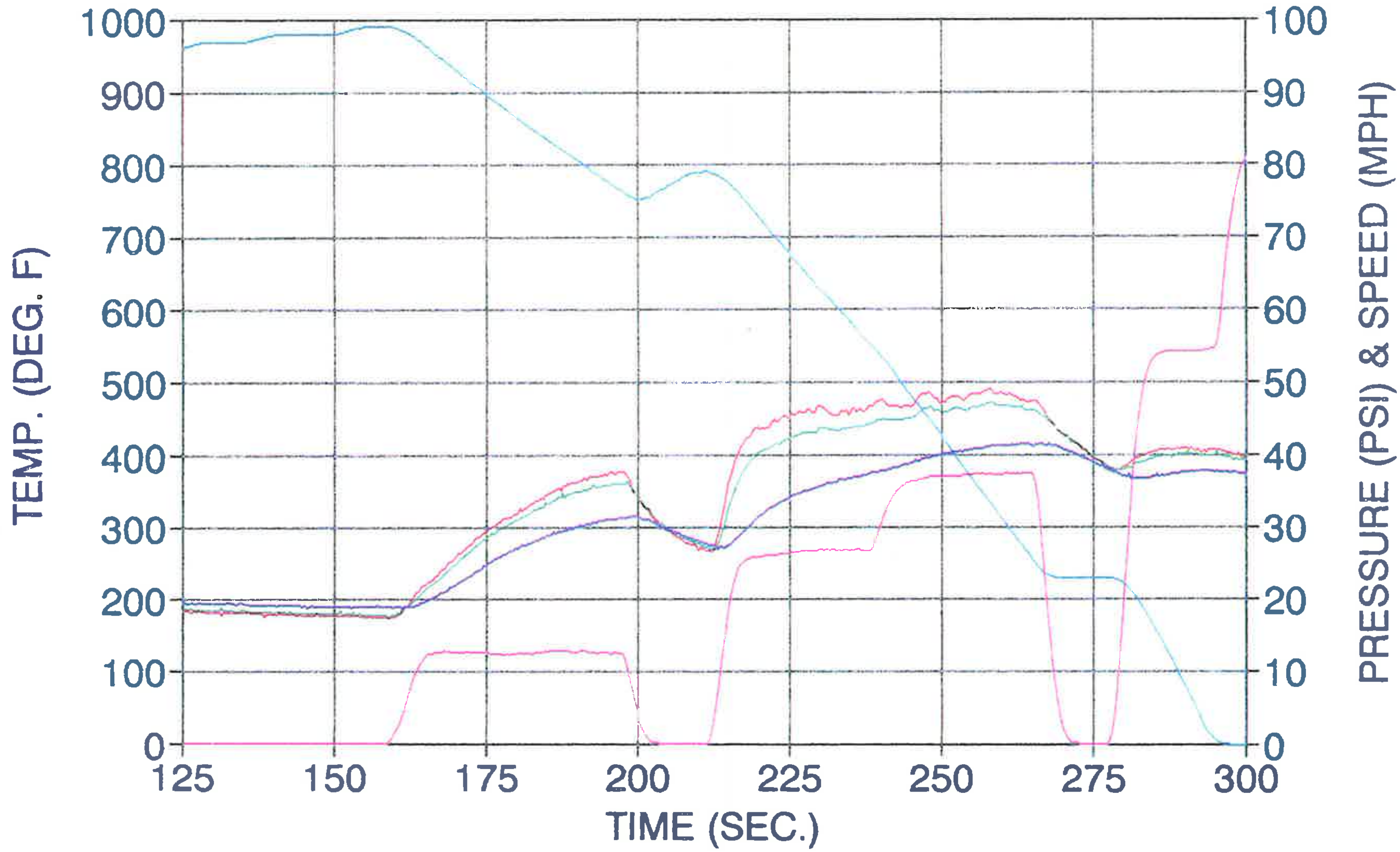
FILE:10220239 WHEEL#:L2 POS.#:7



KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

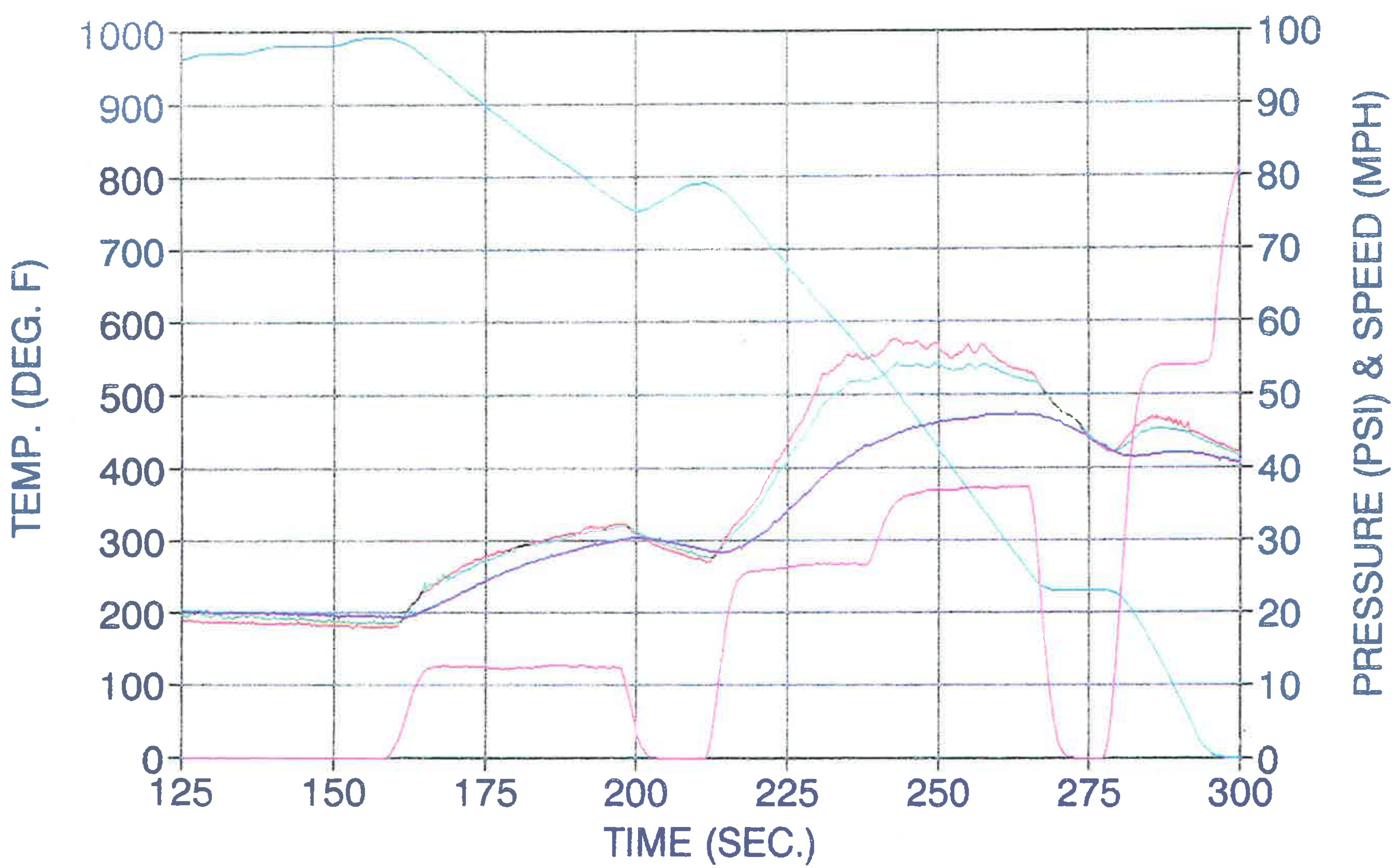
FILE:10220256 WHEEL#:L1 POS.#:4



KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

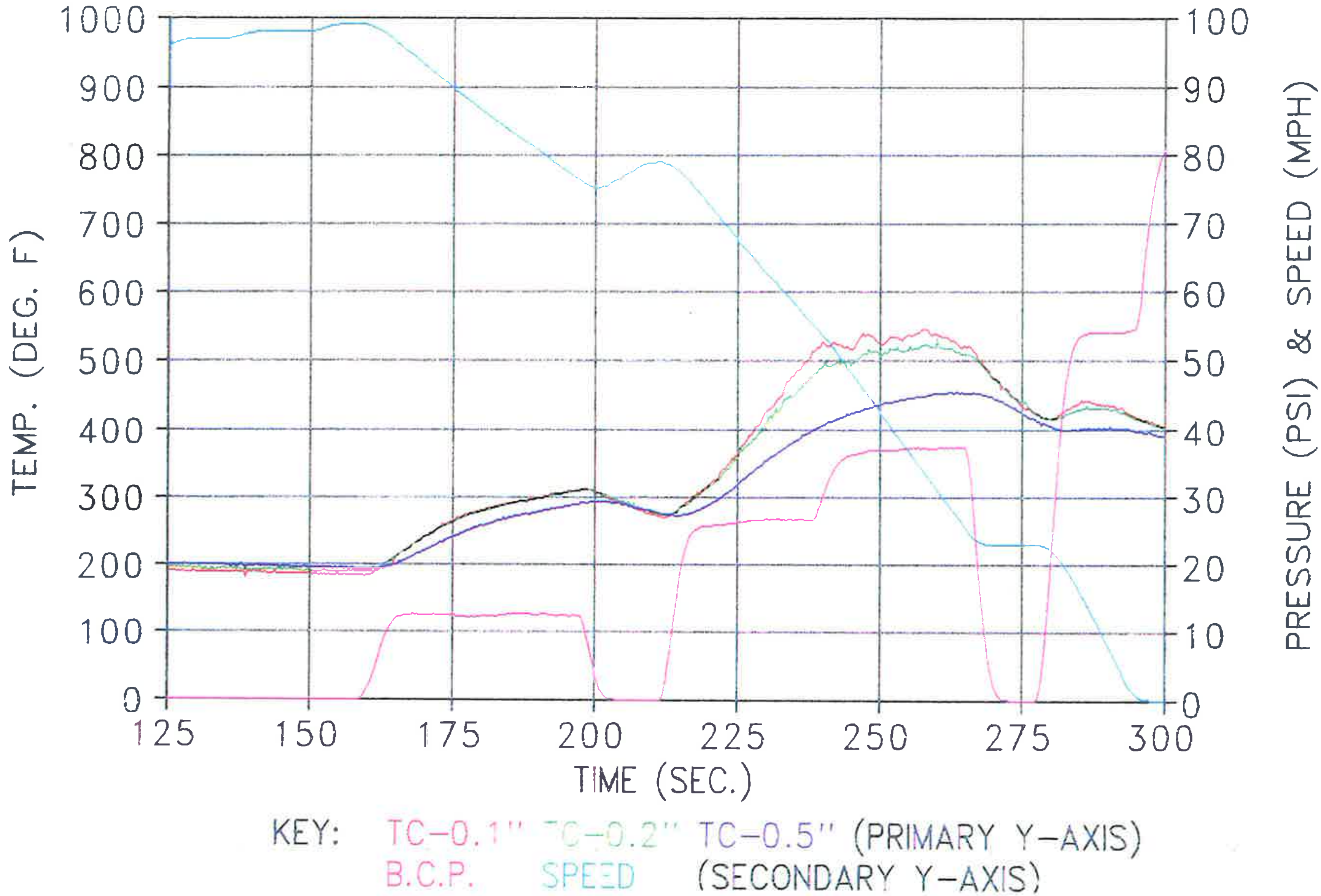
FILE:10220256 WHEEL#:L2 POS.#:6



KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

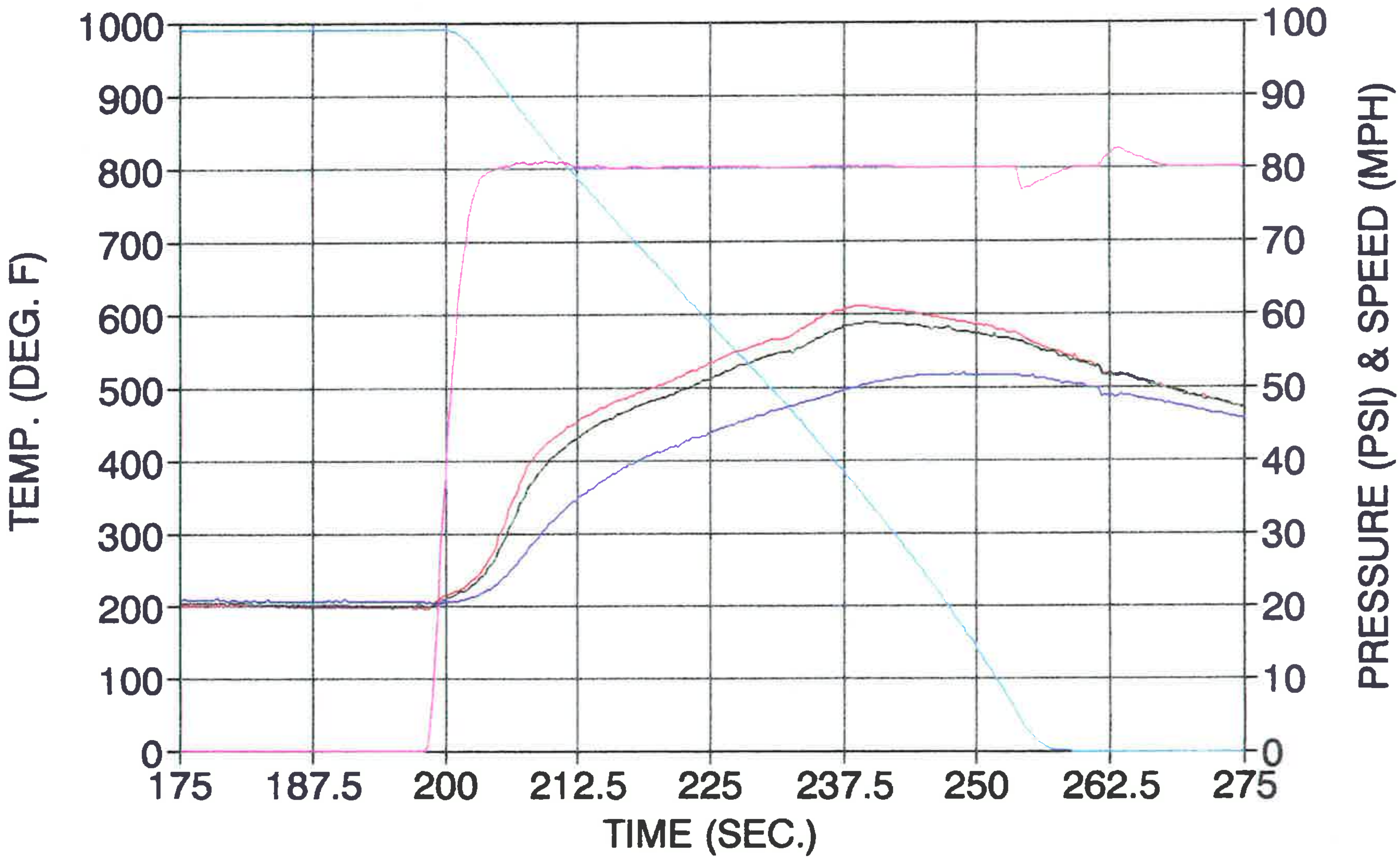
NJT WHEEL TEMPERATURE DATA

FILE:10220256 WHEEL#:L2 POS.#:7



NJT WHEEL TEMPERATURE DATA

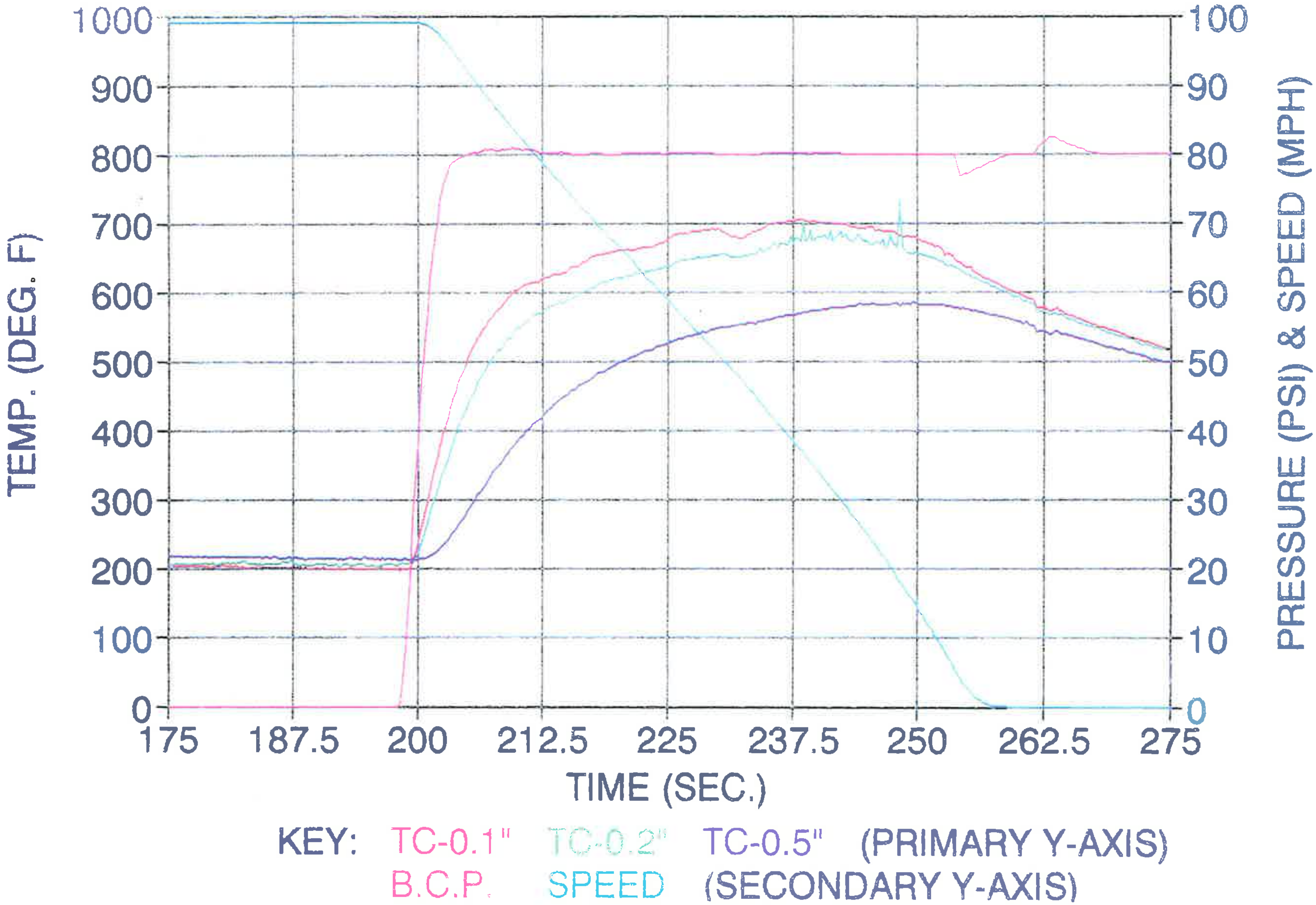
FILE:10220304 WHEEL#:L1 POS.#:4

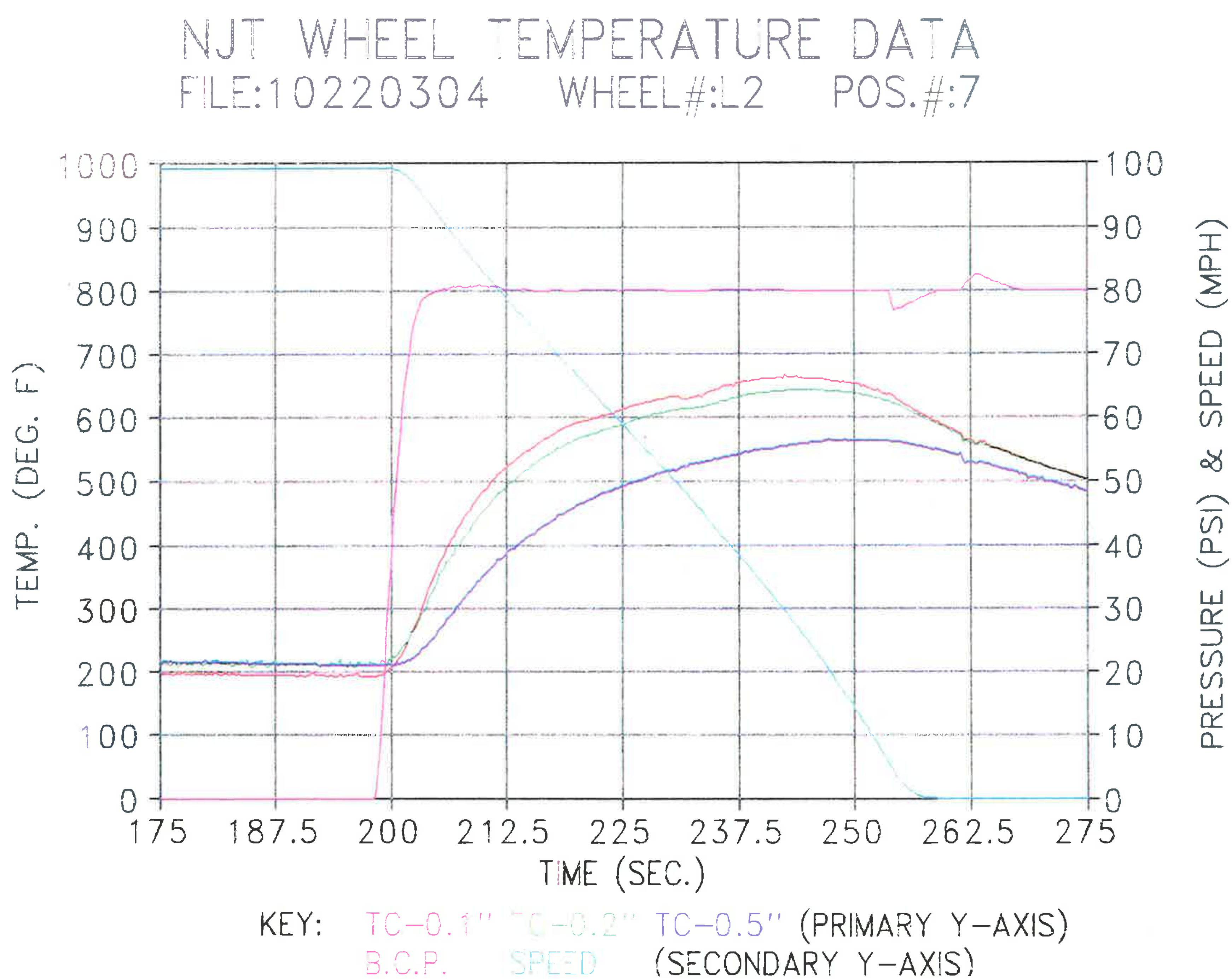


KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

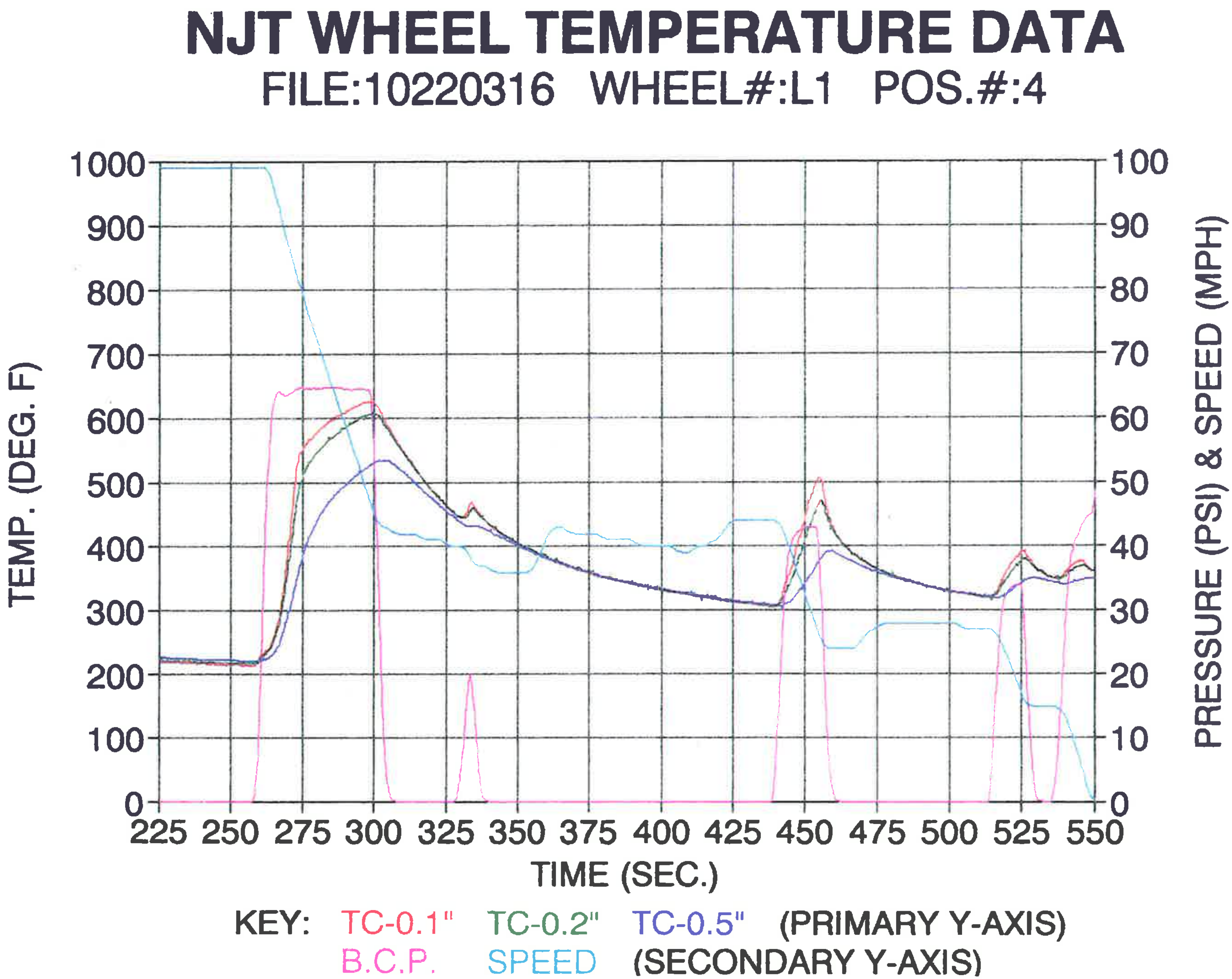
NJT WHEEL TEMPERATURE DATA

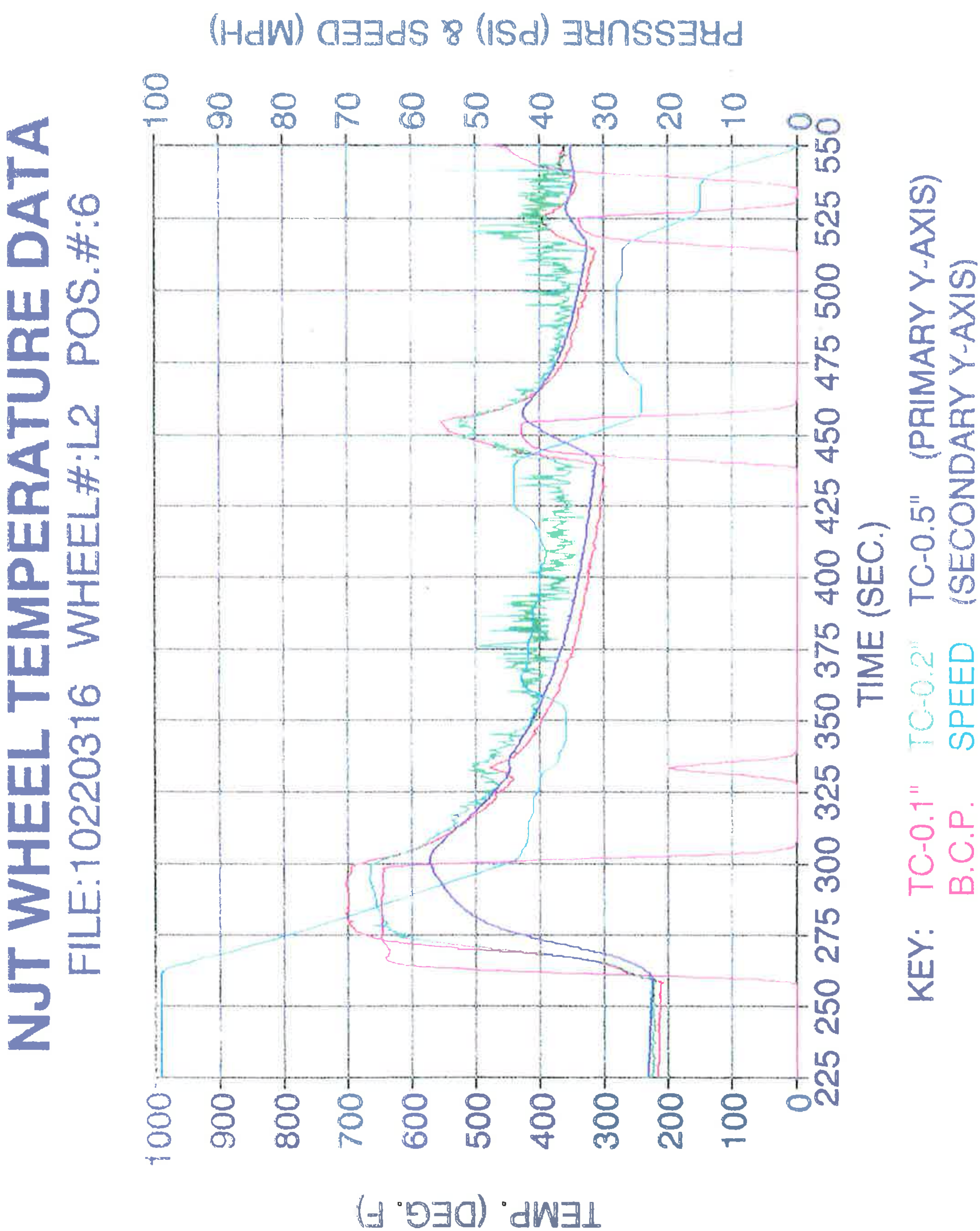
FILE:10220304 WHEEL#:L2 POS.#:6





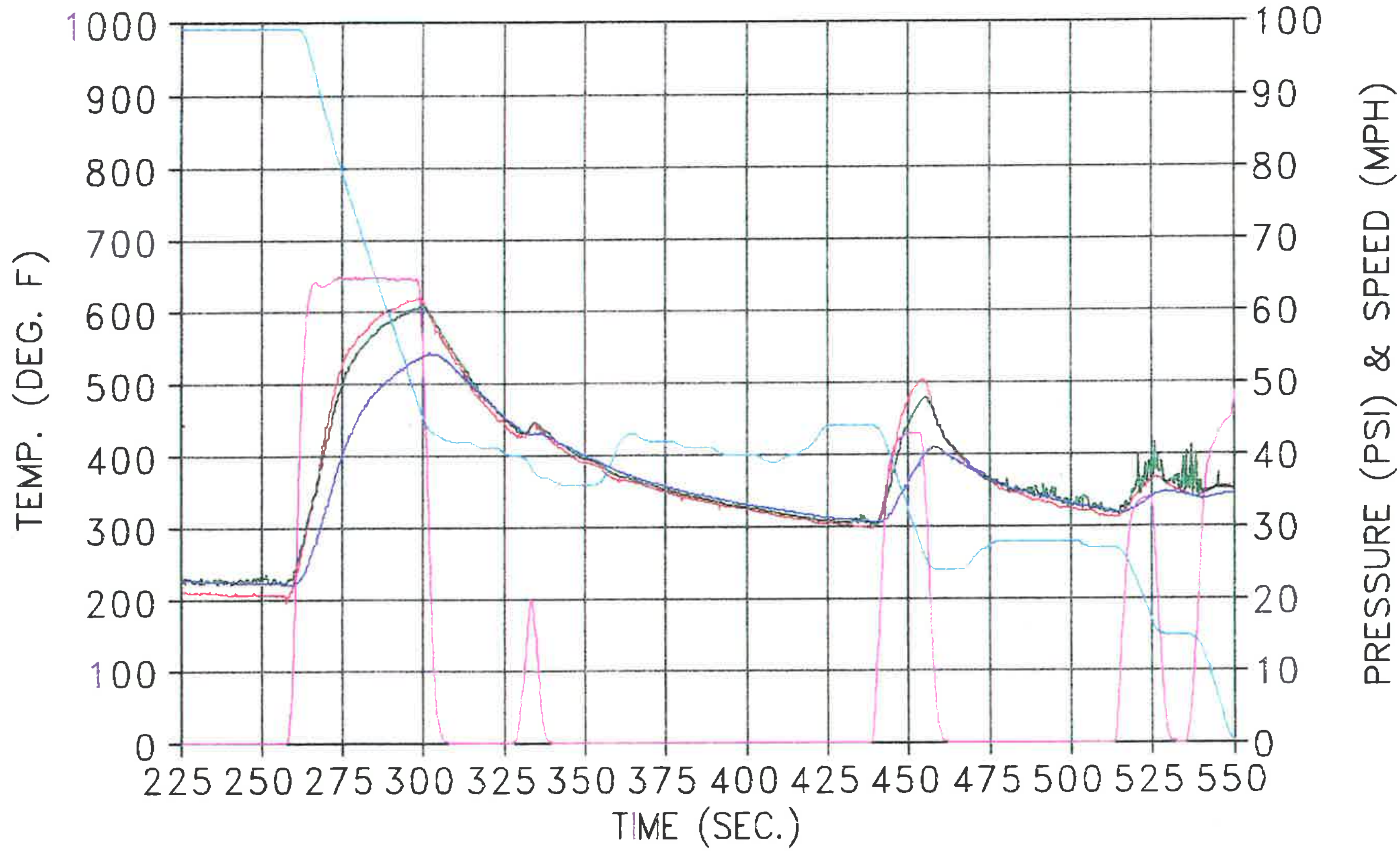
NJT WHEEL TEMPERATURE DATA
FILE:10220304 WHEEL#:L2 POS.#:7
TEMP. (DEG. F)
0 100 200 300 400 500 600 700 800 900 1000
PRESSURE (PSI) & SPEED (MPH)
0 10 20 30 40 50 60 70 80 90 100
175 187.5 200 212.5 225 237.5 250 262.5 275
TIME (SEC.)
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)


NJT WHEEL TEMPERATURE DATA
FILE:10220316 WHEEL#:L1 POS.#:4
TEMP. (DEG. F)
1000
900
800
700
600
500
400
300
200
100
0
PRESSURE (PSI) & SPEED (MPH)
100
90
80
70
60
50
40
30
20
10
0
225 250 275 300 325 350 375 400 425 450 475 500 525 550
TIME (SEC.)
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)


NJT WHEEL TEMPERATURE DATA
FILE:10220316 WHEEL#:L2 POS.#:6
PRESSURE (PSI) & SPEED (MPH)
TEMP. (DEG. F)
TIME (SEC.)
225 250 275 300 325 350 375 400 425 450 475 500 525 550
0 100 200 300 400 500 600 700 800 900 1000
0 10 20 30 40 50 60 70 80 90 100
KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

NJT WHEEL TEMPERATURE DATA

FILE:10220316 WHEEL#:L2 POS.#:7



KEY: TC-0.1" TC-0.2" TC-0.5" (PRIMARY Y-AXIS)
B.C.P. SPEED (SECONDARY Y-AXIS)

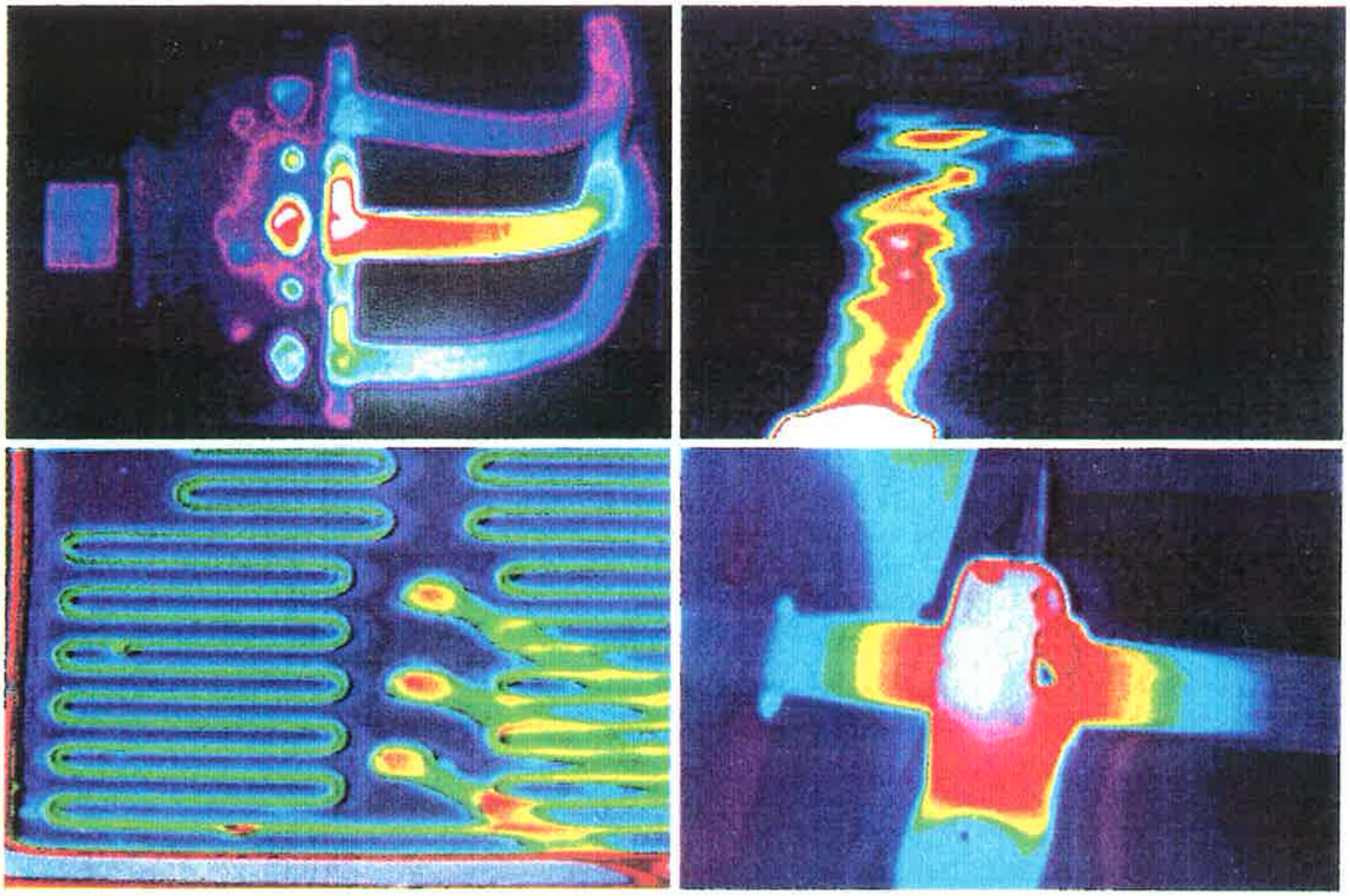
APPENDIX III

INFRARED THERMAL IMAGING REPORT

BAIRD℠ INFRARED TECHNOLOGY, INC.

Specialists in Industrial Diagnostics

Thermal Services Division



Thermographic Inspection

of

NJT Railcar Brake Temperatures

Prepared for
ENSCO, Inc.
Springfield, VA

Project No. P276

Thermographic Investigation Report
of
NJT Railcar Brake Temperatures
for
Ensco, Inc
Springfield, VA
October 21 & 22, 1992

The purpose of this investigation was to determine wheel temperatures of commuter rail cars. New Jersey Transit provided a 6 car train for the tests. The infrared equipment was set up at Princeton Junction Station for the study of the test train. Images of revenue trains (both NJT and Amtrack) were also recorded at Princeton Junction, and later at Metropark Station.

The tests were conducted using an Inframetrics Model 600 thermal imaging system. Data was recorded on VHS videotape and analyzed in our offices using the Inframetrics ThermaGRAM computerized image processing system.

On the videotape, trains are identified by the time they arrived or passed the station. Train or car numbers were recorded where possible or visible. When recording at the Princeton Junction Station, trains traveling left to right were considered west bound. When at Metropark Station, trains traveling right to left were considered west bound. A total list of the trains recorded is shown in Table 2.

Wheel temperatures for the test train were taken from the videotape. An average emissivity (.87) was taken on the instrumented wheels of the test train. This number was used to calculate the temperatures of the other wheels. This emissivity may not be correct for all wheels, and temperatures of other wheels may be off by as much as 20%. To get true temperatures, emissivities should be calculated for all wheels.

Wheel temperatures for the test train are not complete in all cases. When the train was traveling west bound in some cases only the lead car was visible. The rest of the cars were stopped at a position within the station where we were unable to record temperatures. In another case, the train made an emergency stop and came to rest about one-half mile up the tracks again, where temperatures were unobtainable.

Temperatures for the test train and one east bound revenue train are shown in Table 1. Temperatures for the revenue train were corrected for emissivity using the same value (.87) as for the test train. Photographs of typical wheel temperature variation follow the tables.

Respectfully submitted,

Carlton R. Dawson

BAIRD S.M
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Specialists in Industrial Diagnostics

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Wilmington, DE 19801 USA
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Table 1
Thermogram Summary
ENSCO Inc., ,
Oct. 21-22, 1992

No.	Area and Equipment	Temp. Diff., °F	Reference (other)
1	East Bound NJT Train, At 2048, wheels 3 & 4 of Car 6 are shown.		
2	East Bound NJT Train, At 2048, wheels 1 & 2 of car 7.		
3	East Bound NJT Train, At 2048, wheels 1 & 2 of car 4.		
4	Test Train, East bound at 0244, typical wheel temperature.		

Table 2
Trains Recorded

Tape Time	Type of Train	Direction
	At Princeton Junction	
1850	NJT Arrow	WB
1902	NJT	WB
1912	Amtrack Train #60	EB
1923	NJT	WB
1924	Amtrack "Clocker"	WB
1927	Amtrack "Clocker"	WB
1948	NJT (Last Car 1510)	WB
1949	Amtrack "Clocker"	EB
1959	NJT Arrow	WB
2014	NJT (Lead Car 1479)	WB
2017	Amtrack (Engine 912) "Clocker"	EB
2018	NJT (Load Car 1402)	EB
2039	NJT (Head End 4411)	
2046	Amtrack "Clocker"	WB
2048	NJT	EB
2056	Amtrack (Loco 913)	EB
2110	NJT 3865 Train	WB
0011	Amtrack "Clocker"	EB
0012	Test Train	WB
0019	Amtrack	WB
0049	NJT	
0113	Test Train	EB
0145	Test Train	WB
0154	NJT	WB
0244	Test Train	EB
0247	NJT	WB
0307	Test Train	
	At Metro Park Station	
0548	NJT	WB
0549	NJT	EB
0602	Amtrack (Loco 913)	WB
0603	NJT	EB
0614	NJT (#1508)	EB
0626	NJT	WB
0632	NJT	EB
0647	Amtrack (Loco 906)	WB
0648	NJT (Comet)	EB
0653	Amtrack (Loco 924)	WB
0653	NJT	EB
0654	Amtrack "Clocker"	EB
0706	NJT Comet (Loco 414)	EB
0707	NJT	WB
0711	NJT (Lead Car 1353)	EB
0717	Amtrack Metroliner	WB
0720	NJT	EB
0721	Amtrack "Clocker"	EB
0722	Amtrack "Clocker"	WB

Table 3
Wheel Temperatures
(All Temperatures in °F.)

A) Test train, west bound at 0012 a.m.

Car #	Wheels 1	2	3	4
1	75	76	152	160
2	140-160	150	83-97	104-118
3	120	126-133	82-86	77-87
4	124-133	143-165	136-147	126-133

B) Test train, east bound at 0113 a.m.

Car #	Wheels 1	2	3	4
1	203-223	176-184	271	253-271

C) Test train, west bound at 0145 a.m.

Car #	Wheels 1	2	3	4
1	78-85	75-88	60-92	110-127
2	135-140	131-133	126-132	143-153
3	134-142	136-151	102-123	110-114
4	155-170	150-160		
5	154-170	166-170		

D) Test train, east bound at 0244 a.m.

Car #	Wheels 1	2	3	4
1	133	122-133	120-142	142
2	---	162	134	144
3	91-110	128	81-91	133
4	133	136	108	122
5	140-153	104	122	140

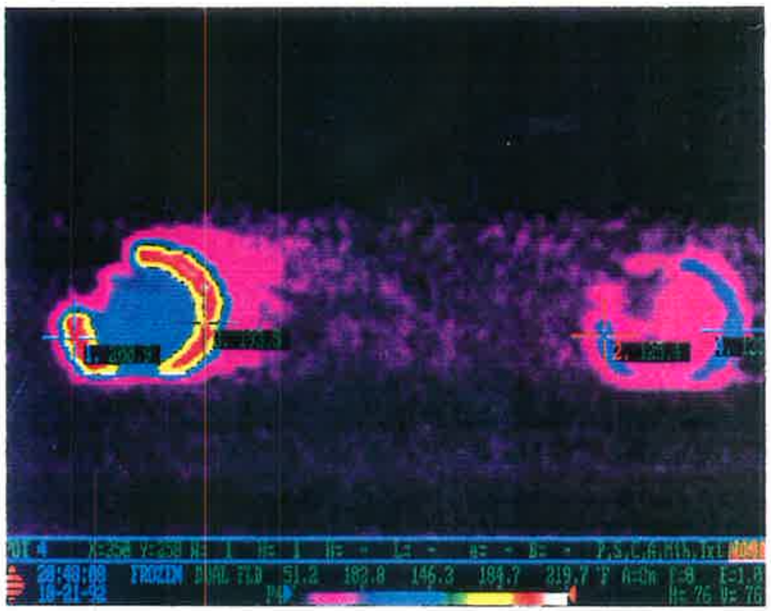
E) Test train, west bound at 0307 a.m.
Data invalid due to condensation on lens.

F) NJT, east bound revenue train at 2048 p.m.

Car #	Wheels 1	Wheels 2	Wheels 3	Wheels 4
1	---	---	---	---
2	---	---	161	172
3	137	150	161	172
4	210	210	184	149
5	189	196	192	195
6	195	199	197	129
7	122	135	180	167
8	196	203	156	148
9	178	169	138	145
10	129	167	162	155
11	91	149	170	159

G) Amtrack, east bound revenue train baggage car. Train at 0019 a.m.

Time	Wheel Temperature
0020:16	180
20:45	154-160
22:13	105-123



Thermographic Report

Oct. 21-22, 1992 1 P276

Area

East Bound NJT Train

Equipment

At 2048, wheels 3 & 4 of Car 6
are shown.

Temperature

Comments

Wheel 3 is approx. 75°F. hotter than wheel 4.

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Thermal Services Division
One Riverwalk Centre, Suite 310
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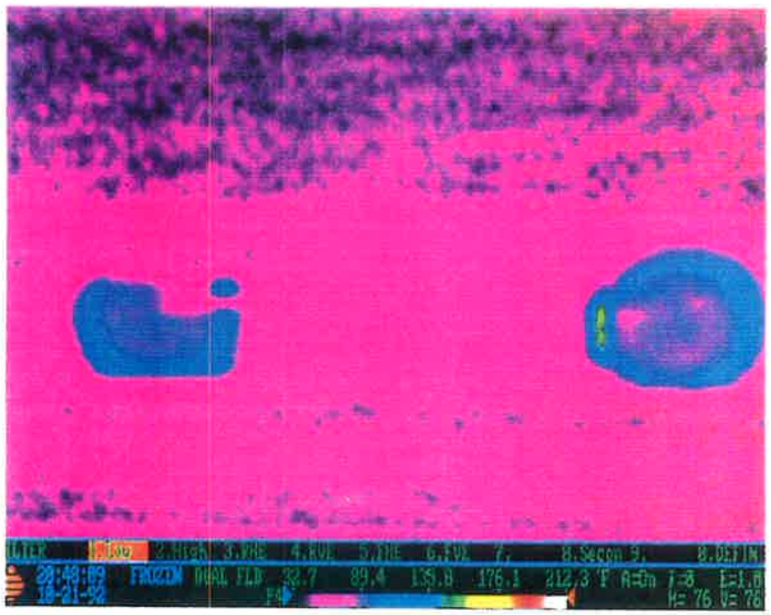
Wilmington, DE 19801 USA
Phone 302/658-7590 • FAX 302/658-3101



Thermographic Report

Oct. 21-22, 1992 2 P276

Area

East Bound NJT Train

Equipment

At 2048, wheels 1 & 2 of car 7.

Temperature

Comments

Wheels are cooler than most. Brake pad is warm.

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Thermal Services Division
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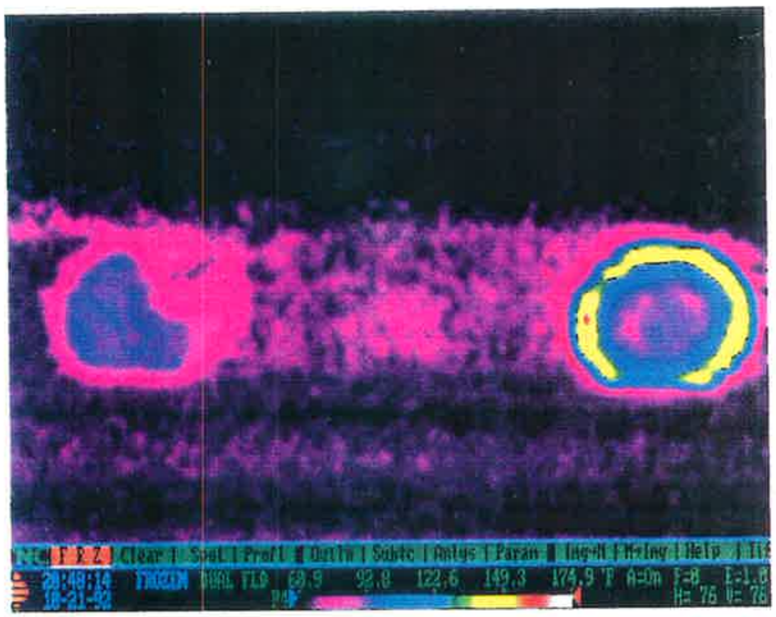
110 South Poplar St.
Wilmington, DE 19801 USA
Phone 302/658-7590 • FAX 302/658-3101



Thermographic Report

Oct. 21-22, 1992 3 P276

Area

East Bound NJT Train

Equipment

At 2048, wheels 1 & 2 of car 4.

Temperature

Comments

Right wheel is approx. 100°F. hotter than the left wheel.

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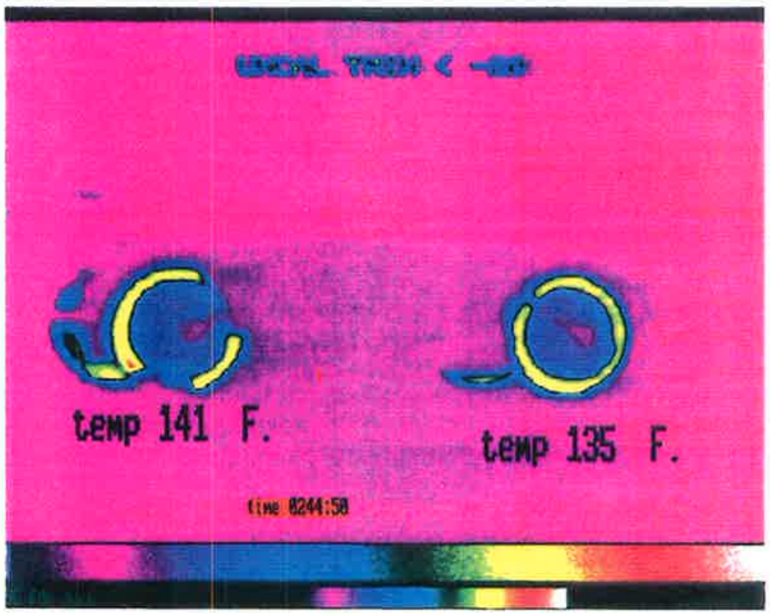

Thermographic Report

Oct. 21-22, 1992 4 P276

Area

Test Train

Equipment

East bound at 0244, typical wheel temperature.

Temperature

Comments

BAIRD[S.M] INFRARED TECHNOLOGY, INC.

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