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U.S. ARMY TACOM

ULTRASONIC INSPECTION FOR ROADWHEEL BONDLINE QUALITY

Final Report

CONTRACT NO. DAAK30-79-C-0121

by I. R. KRASKA
GARD, INC.
NILES, IL 60648

MARCH, 1983

For Public Dissemination, Distribution Unlimited

U.S. ARMY TANK-AUTOMOTIVE COMMAND
Warren, Michigan 48090

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This project was directed at evaluating the feasibility of using ultrasonics, coupled with a unique microprocessor signal analysis and processing system, to determine rebuilt roadwheel quality.

A series of roadwheels were ultrasonically tested, with the data recorded for subsequent computer analysis. The wheels were then either peel, drum, or road tested. A subsequent comparison between certain ultrasonic signal characteristics (signal amplitude and % circumferential phase change) and roadwheel

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Block 20 Abstract (continued)

disposition allowed accept/reject limit selection which provided 80% correct prediction of road failures by ultrasonics, with an 86% overall correct prediction of road test results. When compared to peel results on the same set of roadwheels (60% and 50%), the ultrasonic results are encouraging.

Limitations on conclusions, due to data sample size and related assumptions, are severe. However, further work is indicated, directed at establishing the viability of the described ultrasonic test procedures for both manufacturing quality control and on-vehicle readiness evaluation. The former is already underway. An approach to the latter is suggested.

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SUMMARY

An ultrasonic evaluation of 60 roadwheels, from both acceptable and rejectable production lots, was performed at Red River Army Depot. Each roadwheel was inspected in six passes (three for bondline quality, and three for rubber inclusions). Tape recordings were made from 23 of the 60 roadwheels to allow subsequent computer analysis of the ultrasonic signals with respect to roadwheel performance: 18 in on-vehicle road testing, 3 in peel testing, and 2 in drum testing. No signals indicative of serious rubber inclusions occurred. No failures from inclusions occurred on subsequent tests. Both wheels which passed the drum test had uniform ultrasonic bondline response around their circumference. Three roadwheels which had ultrasonic bondline signal variations were peel tested. Peel test variations correlated with ultrasonic signal changes.

PREFACE

The work described in this report was performed by GARD, INC., a subsidiary of the GATX Corporation, 7449 N. Natchez Avenue, Niles, Illinois 60648 for the US Army Tank-Automotive Command under Contract No. DAAK30-79-C-0121. The work was administered under the direction of Army Project Engineer Chester T. Kedzior of TACOM, Warren, Michigan.

The work covered by this report was performed at GARD in the contractor's Electronic Systems Department, W. L. Lichodziejewski, Manager, by I. R. Kraska Project Engineer and Principal Investigator, with the assistance of T. A. Mathieson and R. A. Groenwald, Research Engineers. The author gratefully acknowledges the assistance provided by Mr. Wallraven, of the Directorate for Quality Assurance, Red River Army Depot (RRAD), in providing the roadwheels used.

This report summarizes the work performed from September, 1979 through October, 1982. It was submitted by the author in November, 1982.

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1.0 INTRODUCTION

Current quality tests for rebuilt roadwheels are peel and drum tests. Each is sampling, destructive, and takes time and effort to perform (days in the case of drum test). A simpler and quicker nondestructive test is needed to assure that a rebuilt roadwheel has good quality. It is desirable that such a test allow 100% inspection, and its results correlate not only with Depot testing, but also with field results.

Previous experience and discussions with Army personnel indicate that the primary mechanisms of failure in wheels are related to rubber blowout and splice separation, and poor bondline adhesion. The blowout and the splice separation problem is induced by unbonded particles in the rubber. Poor bondline adhesion is usually due to material and/or process variations. Both the rubber inclusions and the bad bondline adhesion should be considered in a new inspection test.

Past experience with testing of roadwheels indicates that ultrasonics may be a good approach for the needed quality control test. This program was directed toward showing its feasibility. The unique aspect of this effort was the use of a recently-developed acoustic emission data analysis computer system, based on a Motorola M6800 microprocessor, to extract, permanently record, and analyze ultrasonic roadwheel test information for rubber inclusion and bondline quality indications. GARD used wideband ultrasonic roadwheel recordings, made in the field on a modified video tape recorder, to provide data for analysis on the microprocessor-based computer. The pulse-echo ultrasonic signals were analyzed for instantaneous and average amplitude, frequency content, phase changes, and pulse-type information (ringdown count), and were related to results of dynamometer, peel and road tests to determine feasibility of ultrasonic roadwheel quality prediction.

2.0 OBJECTIVE

The objective of this program is to show feasibility of ultrasonic signal analysis using a special purpose, microprocessor-based computer to determine roadwheel quality. The following specific tasks were performed:

- an ultrasonic data acquisition/recording system was configured for field use.
- GARD's Laboratory microprocessor-based signal analysis system was configured to accept field-recorded ultrasonic data.
- Roadwheels at RRAD were ultrasonically inspected. The signals were recorded for later analysis at GARD.
- The ultrasonically inspected roadwheels were submitted to peel, drum, and road testing.
- The results of the peel, drum, and road tests were compared with computer-analyzed ultrasonic inspections.
- Conclusions about inspection feasibility were formulated.

3.0 CONCLUSIONS

Of the 18 roadwheels monitored on-vehicle, all successfully completed their required 2,000 mile road test. The roadwheels were then subjected to a second road test. Final disposition of these wheels (after an additional 3,300 mile test) was into two classifications: failed (debonded) or passed (chunked, and completed test.

The computer analysis of both the ultrasonic signals and the road, peel, and drum test results indicates a relationship between bondline reflected ultrasonic signals and roadwheel disposition. Averaged circumferential analyses did not provide a relationship. Localized changes in signal amplitude and percent phase inversion did seem to provide a measure of final disposition. Selecting accept/reject limits on both allowed the ultrasonic data to identify 80% of the road-failed wheels (4 of 5) while correctly predicting 86% of road results (12 out of 14). Lot classifications (by peel test) on the same wheels was correct on 60% of the road failed wheels (3 out of 5) with correct prediction on 50% of road results (7 out of 14).

Small sample size, lack of engineering verification of field disposition information, lack of true roadwheel "failures," and lack of really bad "rejectable" lot as an input, makes it hard to draw firm conclusions from this work, except that there appears to be a relationship between ultrasonic signals and final roadwheel disposition.

4.0 RECOMMENDATION

Based upon the favorable results obtained during this program, further work involving larger data samples is recommended to (a) evaluate ultrasonic use as a production quality control tool, and (b) monitor on-vehicle maintenance status. TACOM is already evaluating the former. The latter can be evaluated, in a most effective manner by performing on-vehicle inspections and ultrasonic recordings of vehicles with new roadwheels and planned high mileage use. This approach will avoid a major problem encountered on this program (it took about 2 years to complete the piggy-backed roadwheel road tests described herein).

5.0 SYSTEM DEFINITION

5.1 Background

The basis for the work described in this report was ultrasonic roadwheel inspection performed by GARD on previous efforts. On an Aberdeen Proving Ground monitoring effort, several M60 Tank aluminum roadwheels with known defect areas were inspected with a ultrasonic pulse-echo contact technique. Figure 1 shows resultant oscilloscope recordings of RF pulse-echo ultrasonic traces and their subsequent frequency spectrum analyses. The pictures show ultrasonic signals reflected off the M60 Tank roadwheel bondlines. The difference in signal between "good" and "bad" bond areas in a phase detection mode (amplitude-time signal reflection with the initial signal going negative vs. positive), and a frequency analysis mode (amplitude-frequency distribution in reflected signal with more or less high frequencies present) is evident. Note that while these signal differences are quite obvious, absolute amplitude of signal in the good and bad bond inspection does not vary significantly. Signal amplitude alone is the standard analysis technique used in ultrasonic pulse-echo bondline inspection.

On a visit to RRAD to determine the nature of roadwheel failure GARD inspected 19 roadwheels using ultrasonic pulse-echo techniques, developed on a related GARD/TACOM tire inspection project. We found several wheels with signals indicating large inclusions in the rubber. We marked one suspect wheel as to inclusion location, and had RRAD drum test it. The wheel failed in 58 minutes. The failure started at the marked inclusion area with a brittleness characteristic of the tread blowout and splice separation failures which have caused RRAD quality problems. Sectioning areas of other tread rubber, which produced similar ultrasonic signals, uncovered particles characteristic of the filler material used in rubber manufacturing. Apparently during roadwheel use, these particles generate localized hot spots, embrittle the rubber, and lead to tread failure.

Based upon these results GARD proposed the effort described herein: an evaluation of these signals and their relationship to peel, drum, and field

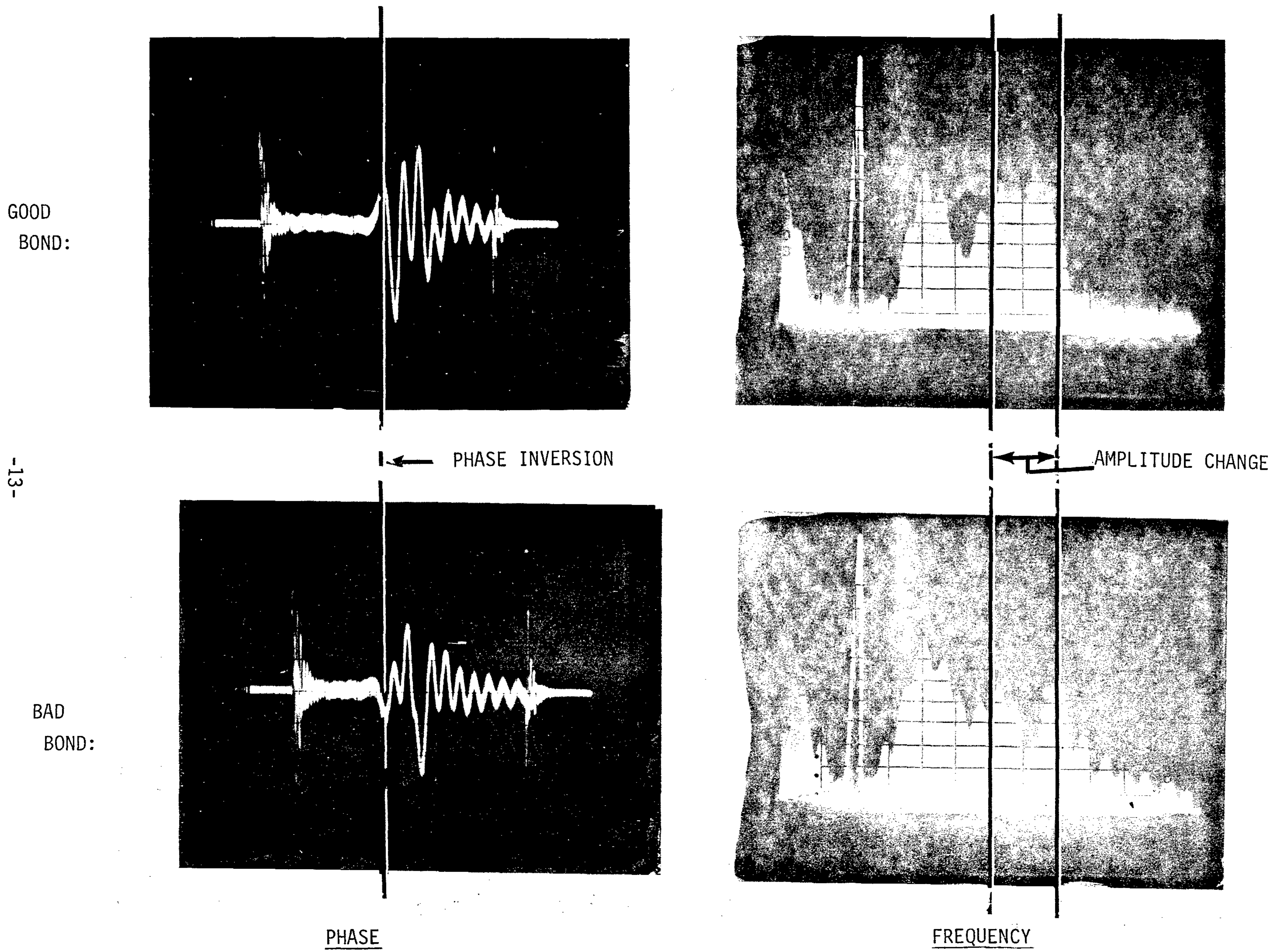


Figure 1 Bondline Evaluation Techniques

test results on candidate roadwheels using an already developed computer-based data analysis system. The remainder of this section describes a) the field system GARD configured to allow Depot-level roadwheel ultrasonic data gathering, b) the computer-based laboratory data analysis system, and c) preliminary data analysis used to check out overall system operation prior to initial Depot inspection data gathering.

5.2 Field System

GARD fabricated an inexpensive, hardened, breadboard ultrasonic pulse-echo inspection system which incorporated transducer positioning requirements to inspect a 5-3/4 inch area (in three passes). The inspection system featured wheel rotation, and incorporated required ultrasonics, computer hardware/software interface, and data recording/playback capability. The field inspection system as implemented is shown in Figure 2.

5.2.1 Inspection Fixture. The inspection fixture contained an immersion tank necessary to couple high frequency ultrasonic energy into the roadwheel. The transducer was attached to a sliding crossway, which allows for adjustment of the position of the transducer to the inspection surface for the wheel. Roadwheel handling was done manually. Roadwheels were lifted, lowered into the water tank and bolted onto the flange of an axle which provided roadwheel rotation relative to the stationary transducer.

5.2.2 Ultrasonics. The instrumentation used to generate ultrasonic inspection signals was centered around a modified Sonics Mark I, which is provided with a 14-pin accessory connector on its rear panel. This made available some of the power supply voltages used by the Sonics, as well as Transistor-Transistor Logic (TTL) compatible gate signal. This active-low signal indicates the time interval of the internally generated gate, and was used in this application to gate the RF data to a video tape recorder. Two pairs of unused pins were wired to make two internal Sonics signals available externally. The first pair provided the RF signal found at the Receiver P/C board. Obtaining this signal before the "detector" permits phase detection of the ultrasonic reflected signal, to be used for bond/debond discrimination. The second pair was wired to the sweep board, enabling the synchronizing of the Sonics rep-rate with the 60 Hz power line.

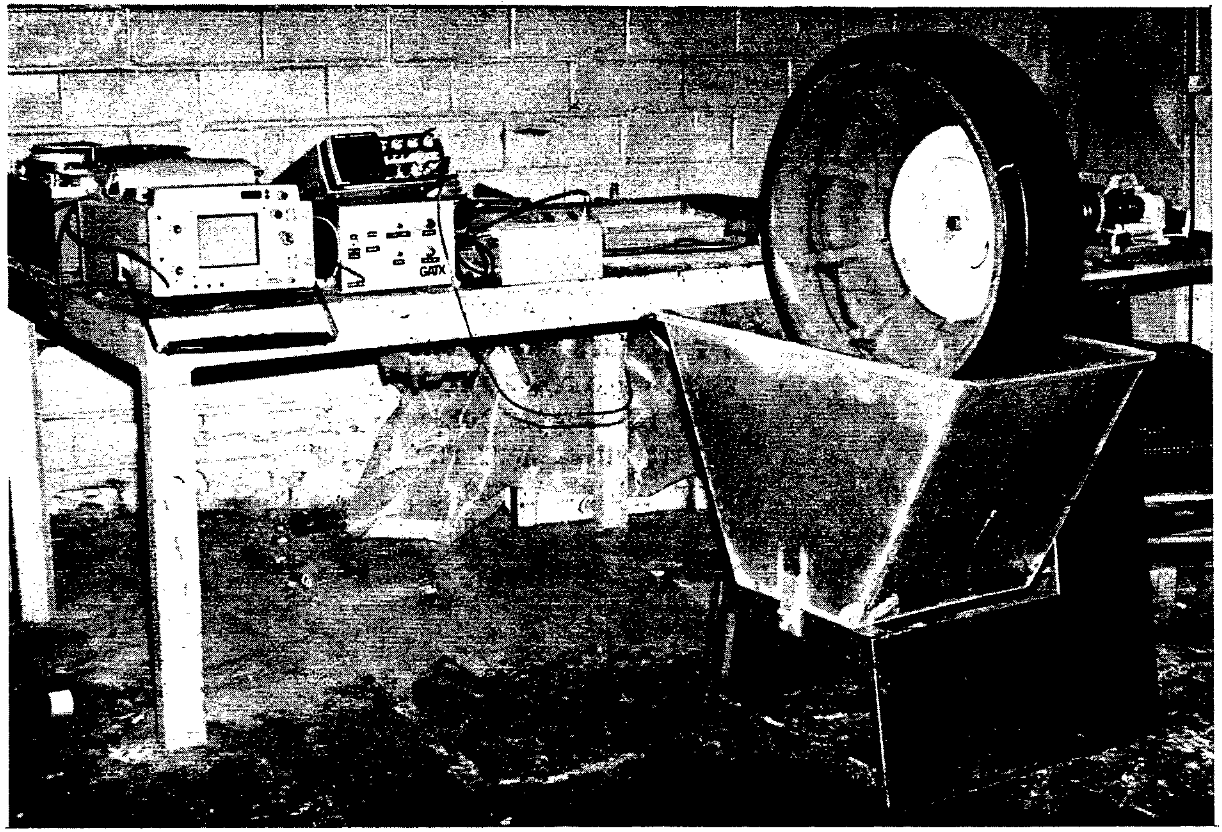


Figure 2 Field Ultrasonic Roadwheel Inspection Recording System

5.2.3 Interface. An interface was breadboarded to provide the following functions:

1. Receive the RF data from the Sonics unit, and provide required voltage gain and power drive ability to drive the low (75Ω) input of a video tape recorder (VTR).
2. Using a high speed solid-state analog switch, enable the RF data to the video tape unit only during the gate interval defined by the Sonics unit.
3. Generate a 120 Hz line sync signal to control the Sonics rep-rate oscillator.

The interface was also provided with the ability to start and stop this data pulse transmission to the VTR. This could be done manually or automatically (synchronized with wheel rotation) to allow precisely one rotation of wheel data to be recorded.

5.2.4 Video Tape Recorder. A Sony AV3650 video tape recorder, as adapted previously by GARD for Acoustic Emission (AE) data recording, was used for this application. Modifications included increase of dynamic range by removing signal clamping diodes, and forcing a 60 Hz interval sync to the head drum motor.

5.3 LAB System

GARD has developed and is currently using a unique computer-aided data analyzer for various acoustic emission and ultrasonic investigations. It forms the basis for the ultrasonic roadwheel analysis performed on this program, and is shown in Figure 3. The system is composed of preprocessor, a microcomputer, and a floppy disk mass storage device. The preprocessor monitors amplified acoustic signals, converts it to ringdown counts, samples voltages being held in peak detectors tied to the outputs of eight frequency filter circuits, and presents the results to the microcomputer in a digital form. The microcomputer processes, stores, and displays the preprocessor results.

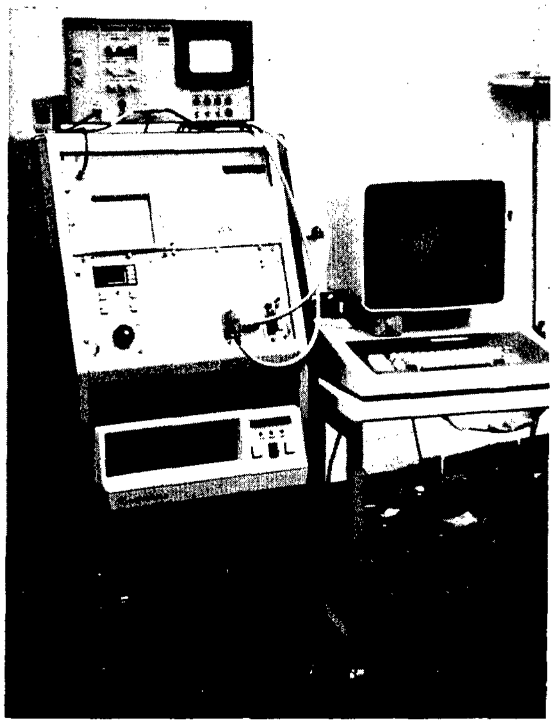


Figure 3 Ultrasonic Computer Data Analysis System

When the data are transferred from the preprocessor, they are organized into a format for storage to disk. This format is a collection of twelve computer words of "bytes" arranged in the following way. The first two bytes stored to or read from disk represent the number of computer-generated display sweeps which has elapsed since the previously recorded event. The next two bytes are a combination input composed of a 12-bit representation of the ringdown count and 4 bits representing the status of four flags used by the preprocessor logic. These flags and their significance are summarized in Figure 4. Each of the final eight bytes in the disk format is an 8-bit representation of the voltage sensed in one of the eight frequency bands analyzed. The ordering of these bytes in the format is 920 kHz, 675 kHz, 500 kHz, 370 kHz, 270 kHz, 200 kHz, 150 kHz, and 110 kHz.

Once the data have been accepted and stored by the microcomputer, a number of analyses can be performed. Most of these analysis procedures provide graphed summaries of acoustic energy distributions, accumulated activity in the monitored frequency bands, or time-based plots of these parameters. An elementary statistics and tabulation package is included to aid in trend analysis. The capabilities of the analysis system are summarized in Figure 5. Figure 6 shows a typical statistical file analysis.

This system allows practical signal analysis of the large amount of data generated by the circumferential ultrasonic inspection of a roadwheel. Analysis is centered around pulse energy (ringdown count) indication of inclusion presence, and broadband peak signal amplitude, frequency content, and phase state indications of bondline quality. The system was used as is, except for an input hardware/software modification to allow broadband bondline signal amplitude indication in the 920 kHz printout column, and signal phase indication in the first two flag columns.

FLAG	SIGNIFICANCE
Counts	Set when ringdown count is greater than 100. Otherwise clear.
Overflow	Set when ringdown count is greater than 1000. Otherwise clear.
Frequency	Set when flaw frequency criterion is satisfied. Otherwise clear.
Alarm	Set as a result of logical processing of above three flags and timing factors associated with event. Otherwise clear.

Figure 4 Preprocessor Flag Description

ENERGY RELATED

Accumulative ringdown count distribution for all events
Accumulative ringdown count distribution when preprocessor alarm is set
Accumulative ringdown count distribution when preprocessor counts is set
Accumulative ringdown count distribution when preprocessor overflow is set
Accumulative ringdown count distribution when preprocessor frequency is set

FREQUENCY-RELATED

Accumulative activity for eight frequency bands:

110 KHz	150 KHz
200 KHz	270 KHz
370 KHz	500 KHz
675 KHz	920 KHz

TIME-RELATED

Events satisfying selected ringdown count and preprocessor flag criteria
Activity for any one of above frequency bands

STATISTICAL

Tabulation of time of occurrence, interval time, ringdown count, frequency band activity, and preprocessor flag status for events satisfying selected energy and time criteria

Averaging of ringdown counts and frequency band activity for events satisfying selected energy and time criteria

Normalization of frequency band activity to the activity in a selected band

Figure 5 Capabilities of the Analyzer System

04 ROADWHEEL 4, M 97, 0 DB, 0-5 RDC/16 1035

	RDC	110	150	200	270	370	500	675	920
NORMALIZING AVERAGE		0.19	0.51	0.33	0.40	0.45	0.35	0.11	1.00
AVERAGE	0001	96	253	165	196	221	172	54	487
STANDARD DEVIATION	0	19	67	30	33	4095	13	10	69

NUMBER 188

TIME LIMITS :	00:00:00 - 21:50:70	RINGDOWN COUNTS LIMITS :	0 - 65535
110 KHZ LIMITS :	1 - 65535	150 KHZ LIMITS :	1 - 65535
200 KHZ LIMITS :	1 - 65535	270 KHZ LIMITS :	1 - 65535
370 KHZ LIMITS :	1 - 65535	500 KHZ LIMITS :	1 - 65535
675 KHZ LIMITS :	1 - 65535	920 KHZ LIMITS :	1 - 65535
LOCATION LIMITS :	0 - 65535	KEYBOARD ENTRY :	1

Figure 6 File Analysis

5.4 Laboratory Evaluation

Ten TACOM-provided roadwheels were inspected in the laboratory for test development and instrumentation checkout of the system described in Section 5.3. The System is shown in use in Figure 7.

Experiment showed these wheels contained no debond conditions which could be used for "setup" purposes. Two standard "bond" and "debond" samples, were then fabricated to provide typical signal changes associated with ultrasonic inspection of good/bad bonds. Two 1 inch thick rubber blocks were bonded to a 1/4 inch thick steel plate, in a manner to generate one bonded and one debonded interface.

The presence of the bond and debond condition in the samples were verified by inspection with the contact pulse-echo ultrasonic test developed previously by GARD for rubber/steel bondline inspection. An example of bond and debond ultrasonic signals from the test samples is shown in Figure 8. Comparison of the received signal from a bonded area (Figure 8a) and debonded area (Figure 8b) shows the change in amplitude (y-axis variation) to be small. However, there is a very obvious phase inversion (leading edge, y-axis crossing) which can easily be monitored to reliably detect the debonds.

Initial checkout of the system was performed on these bond/debond samples. Figure 9 is a copy of the printout of the computer analysis of the recorded ultrasonic signals. The first column is the time interval between the data sampling points. The next column is the ringdown count of the signal. Then we have the 7 frequencies (kHz) investigated. The "920" channel serves as the broadband spectrum peak amplitude monitor. No 920 kHz frequency analysis was performed even though we were using a 1 MHz transducer, because prior work with rubber has shown there is no reasonable level of reflected signal at 920 kHz due to high frequency signal attenuation by 4 inches of rubber.

The LOC column is not used. In the AOCF column only the first two digits are used. These digits identify phase information of the reflected bondline signal: 01 indicates a bond condition, 10 a debond condition, and 11 a transitional condition. The last column, KE, is the keyboard entry. It is used for "notes" by the operator. In this case, B is used to identify the inspection of a bonded sample, and D the inspection of debond sample.

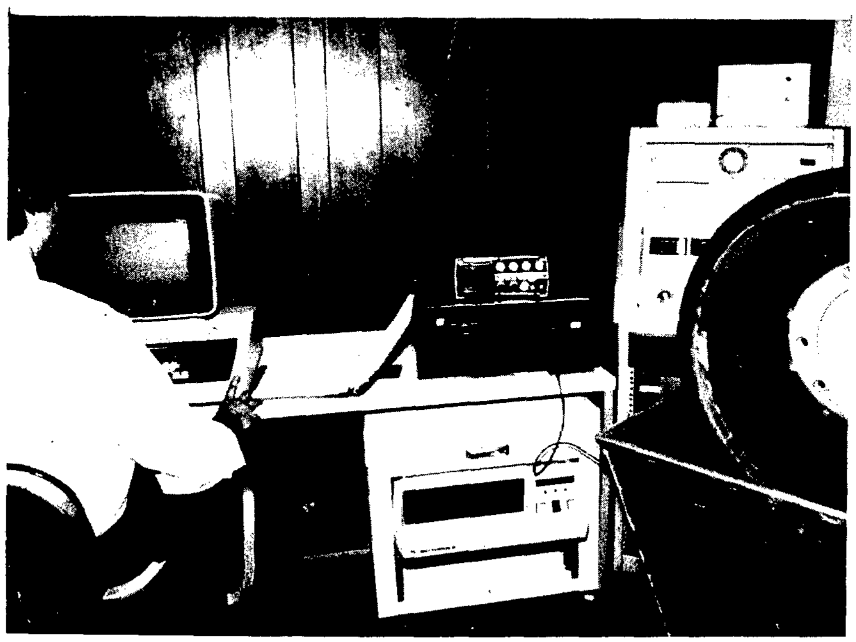
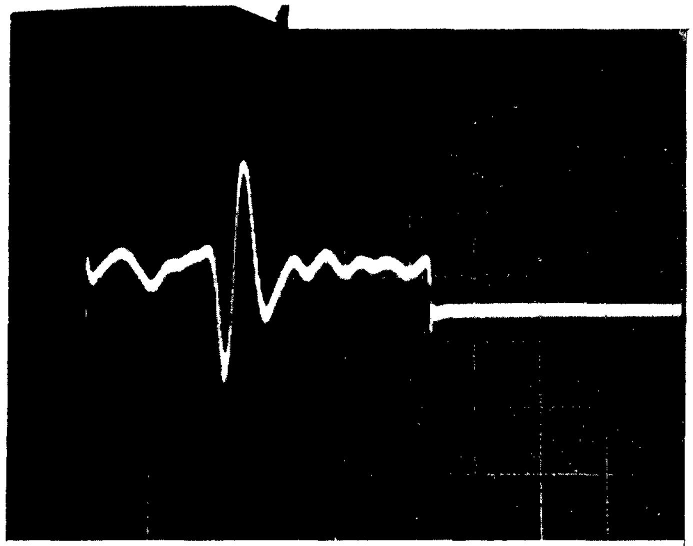
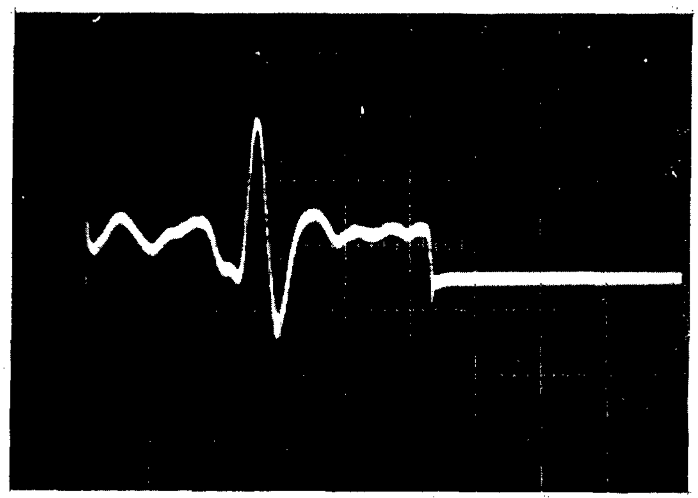


Figure 7 Roadwheel Computer Analysis System



8a Bond Area



8b Debond Area

Figure 8 Ultrasonic Reflection from a Rubber to Steel Bondline

13 STANDARD TAPE - B/D, M97, ODB, 0-5RDC/64 93

TIME	INTERVAL	RDC	110	150	200	270	370	500	675	920	LOC	AOCF	KE
00:36:92	00:00:54	1	130	496	144	117	202	249	159	523	0	0101	B
00:37:38	00:00:46	1	125	486	137	116	198	243	155	507	0	0101	B
00:37:90	00:00:52	1	130	497	143	115	202	250	159	523	0	0101	B
00:38:40	00:00:50	1	132	498	140	118	194	250	157	524	0	0101	B
00:38:90	00:00:50	1	127	489	133	118	214	244	152	509	0	0101	B
00:39:36	00:00:46	1	126	482	141	111	199	244	157	508	0	0101	B
00:39:84	00:00:48	1	126	485	137	116	200	243	148	508	0	0101	B
00:40:34	00:00:50	1	127	490	138	118	205	243	154	509	0	0101	B
00:40:80	00:00:46	1	125	479	144	108	189	243	156	507	0	0101	B
00:41:30	00:00:50	1	128	485	143	113	193	243	157	508	0	0101	B
00:41:78	00:00:48	1	125	487	134	118	200	243	154	510	0	0101	B
00:42:28	00:00:50	1	126	493	138	114	203	247	156	517	0	0101	B
00:42:76	00:00:48	1	129	502	143	118	203	251	159	525	0	0101	B
00:43:26	00:00:50	1	128	499	144	115	197	251	162	525	0	0101	B
00:43:76	00:00:50	1	130	498	141	118	205	250	160	526	0	0101	B
00:44:22	00:00:46	1	128	485	141	112	199	244	154	510	0	0101	B
00:44:74	00:00:52	1	127	493	141	116	208	248	155	517	0	0101	B
00:45:22	00:00:48	1	125	480	141	108	202	244	155	509	0	0101	B
00:45:70	00:00:48	1	129	499	141	121	208	250	161	526	0	0101	B
00:46:18	00:00:48	1	127	486	141	114	195	244	156	510	0	0101	B
00:46:68	00:00:50	1	128	490	135	117	201	244	157	509	0	0101	B
00:47:16	00:00:48	1	126	485	137	111	200	244	156	509	0	0101	B
00:47:62	00:00:46	1	127	484	136	114	187	244	155	510	0	0101	B
00:54:00	00:06:38	0	0	0	0	0	0	0	0	0	0	0000	D
01:05:96	00:11:96	1	120	474	135	116	199	239	158	497	0	1001	D
01:06:46	00:00:50	2	56	414	112	106	225	219	167	463	0	1001	D
01:06:96	00:00:50	2	58	423	108	106	218	221	164	472	0	1001	D
01:07:44	00:00:48	2	59	419	115	108	231	226	171	478	0	1001	D
01:07:94	00:00:50	2	59	425	115	113	235	229	177	486	0	1001	D
01:08:40	00:00:46	2	59	417	112	111	231	224	172	471	0	1001	D
01:08:90	00:00:50	2	60	418	114	108	234	227	174	477	0	1001	D
01:09:40	00:00:50	2	56	413	118	105	219	220	170	475	0	1001	D
01:09:88	00:00:48	2	58	426	116	111	230	231	177	488	0	1001	D
01:10:40	00:00:52	2	67	418	114	111	222	226	171	480	0	1001	D
01:10:88	00:00:48	2	50	425	111	113	244	230	175	487	0	1001	D
01:11:38	00:00:50	2	55	425	115	112	239	230	177	487	0	1001	D
01:11:86	00:00:48	2	58	413	113	107	225	224	172	472	0	1001	D
01:12:34	00:00:48	2	62	414	113	107	220	224	169	473	0	1001	D
01:12:84	00:00:50	2	61	413	116	107	218	224	169	473	0	1001	D
01:13:30	00:00:46	2	56	413	112	112	233	224	174	472	0	1001	D
01:13:82	00:00:52	2	50	414	109	108	230	224	172	473	0	1001	D
01:14:28	00:00:46	2	56	412	114	109	233	225	169	472	0	1001	D
01:14:76	00:00:48	2	64	413	108	107	220	224	169	474	0	1001	D
01:15:24	00:00:48	2	56	414	112	109	229	224	172	474	0	1001	D
01:15:72	00:00:48	2	57	413	110	108	230	225	170	473	0	1001	D
01:16:22	00:00:50	2	62	413	112	105	224	224	172	472	0	1001	D
01:16:72	00:00:50	2	54	413	109	109	232	225	174	472	0	1001	D
01:17:22	00:00:50	2	61	426	115	112	231	231	178	488	0	1001	D
01:17:70	00:00:48	2	62	428	113	112	232	231	176	487	0	1001	D
01:18:20	00:00:50	2	56	426	110	114	240	231	175	487	0	1001	D

Figure 9 Computer Analysis of Standard Bond/Debond Sample

6.0 DATA ACQUISITION/ROADWHEEL SELECTION

The above described field inspection system was taken to Red River Army Depot. The primary objective of the trip was to select candidate roadwheels for future road testing. The secondary objective was to identify several wheels for peel testing and drum testing. Wheels would be selected from those available for inspection at the time of the trip. Because of circumstance, GARD had available a selection of wheels from two Red River lots: marginally rejectable, and acceptable. Inspection data were recorded for later computer analysis on the wheels selected for drum, peel and road tests.

6.1 Rubber Inclusions

Sixty M60 Tank roadwheels were ultrasonically inspected for rubber inclusions by visual inspection of gated signals from the rubber portion of the wheels. No large groups of inclusions/porosity were evident. Many of the wheels did contain one or two isolated indications of inclusions/porosity but, based upon previous experience, these were not significant enough to cause roadwheel failure. Therefore no evaluation of the recordings was performed. As expected, no subsequent test results/failures related to inclusions occurred.

6.2 Bondlines

Of the 60 roadwheels inspected, tape recordings were made of bondline signals for 23 wheels. Of these 23 wheels, based upon visual interpretation of gated signals, 18 were selected for road testing, 3 for peel testing, and 2 for drum testing.

Figure 10 is a summary of the visual ultrasonic results and their utilization as to subsequent test type. The M series wheels were from a "good" new production lot. The G and J wheels were from lots which marginally met peel test requirements, but were graded "For Conditional Use" by Red River. The last two wheels in the list are steel; the others are aluminum.

Roadwheel #		Ultrasonic Results	Test Disposition		
SN	GARD		Peel	Drum	Road
M941935	23	No Irregularities			✓
M941936	21	No Irregularities			✓
M942323	20	No Irregularities			✓
M942240	18	No Irregularities			✓
M942246	19	No Irregularities			✓
M942276	22	No Irregularities			✓
G926543	10	No Irregularities			✓
G926352	6	No Irregularities			✓
G926294	2	No Irregularities			✓
J931009	5	No Irregularities			✓
J931012	3	No Irregularities			✓
J931044	9	No Irregularities			✓
J931045	4	No Irregularities			✓
J931179	7	Phase Inversion/8"			✓
J930852	8	Irregularities/Apparent Frequency Shift			✓
G926209	15	Large Irregularities/45° Phase Shift			✓
G926609	12	180° Amplitude Change			✓
G926468	14	Phase Inversion (1" Diameter)			✓
G926426	1	Small Phase Shifts	✓		
G926467	11	180° Amplitude Change	✓		
G924667	13	Large Change in Localized Area	✓		
M941328	24	No Irregularities		✓	
M942903	25	No Irregularities		✓	

Figure 10 Visual Ultrasonic Inspection Results

7.0 DATA ANALYSIS/TEST RESULTS

As described in the previous Section, 23 roadwheels were selected for testing (18-road, 3-peel, and 2-drum). Circumferential ultrasonic bondline data were recorded for them in format compatible with subsequent laboratory computer analysis. This analysis would attempt to determine feasibility of ultrasonic prediction of roadwheel bondline integrity as defined by peel, drum, and road test results.

7.1 Peel Test

The three candidate roadwheels were peel-tested. These wheels were from a marginally acceptable lot. Subsequent peel tests showed that areas on these wheels had 400# adhesion, where 800# is considered good and about 360# is minimum acceptable strength. (The exact minimum depends upon the actual width of the wheel, which can vary from 5-1/4 inches to 5-3/4 inches.)

Figure 11 is a peel test recording of one of these roadwheels. Figure 12 is a computer printout of ultrasonic data from the circumference of the same roadwheel. A comparison of these figures shows that an ultrasonic signal change occurs in the same areas that the peel test shows bond strength change, in several of the signal analysis channels (110, 270, 500, and 920). For example, in the broadband channel (920) the signal amplitude for good bond averages about 490 while the signal amplitude for the weak bond averages about 400. This drop in signal amplitude correlates with the observed signal amplitude monitored on the oscilloscope during the ultrasonic testing of the roadwheel. The location of these changes in bondline reflected signals were marked on the roadwheel prior to peel test. Results of the peel test showed that areas of the wheel that had higher signal amplitudes were well bonded (800#) while in areas of poor bond (400#) the signal amplitude was lower.

Comparable signal variations represented by Figures 11 and 12, occurred in the other 2 peel-tested wheels. This result is classified as a successful indication of potential correlation of ultrasonics and bondline variations. However, no final decisions as to technique feasibility can be made because of our small data base. An in-depth evaluation of this approach is warranted.

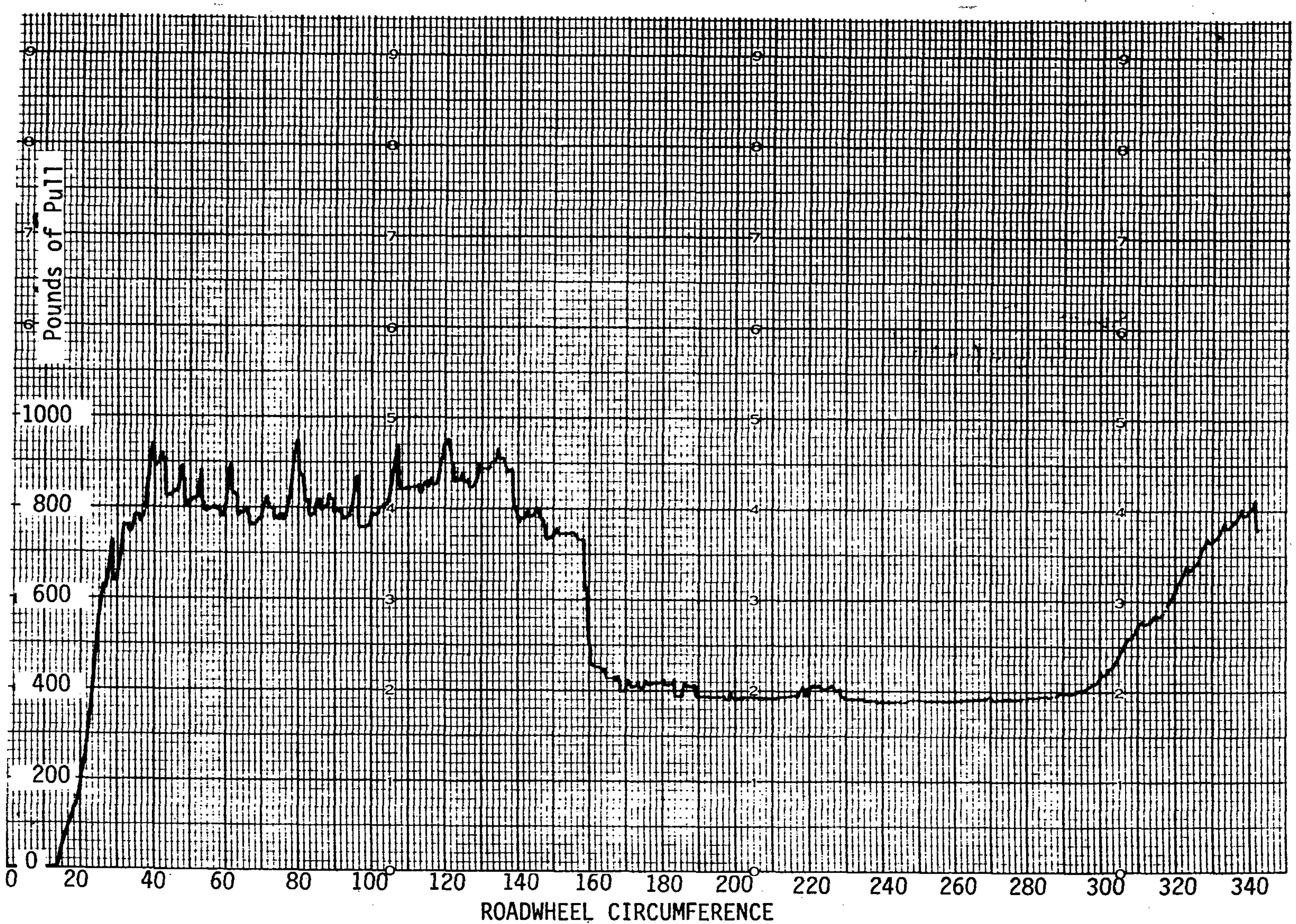


Figure 11 Peel Test Recording of a Roadwheel From A Rejected Production Lot

06 RW11, M97, ODB:0-5RDC/64 - FGW PASS 2 53

TIME	INTERVAL	RDC	110	150	200	270	370	500	675	920	LOC	AOCF	KE
00:01:34	00:01:34	0	0	0	0	0	0	0	0	0	0	0000	2
00:46:32	00:44:98	2	112	193	160	143	194	133	45	439	0	0101	2
00:46:84	00:00:52	2	133	209	183	160	206	150	45	486	0	0101	2
00:47:36	00:00:52	2	138	233	194	167	218	157	52	503	0	0101	2
00:47:80	00:00:44	2	142	240	194	166	208	151	48	495	0	0101	2
00:48:30	00:00:50	2	139	237	196	165	202	148	48	481	0	0101	2
00:48:76	00:00:46	2	130	213	187	159	196	146	50	465	0	0101	2
00:49:24	00:00:48	2	124	228	188	164	183	144	57	454	0	0101	2
00:49:74	00:00:50	2	109	208	178	158	172	136	53	423	0	0101	2
00:50:22	00:00:48	2	104	187	172	152	170	130	47	398	0	0101	2
00:50:70	00:00:48	2	109	192	171	153	181	130	46	407	0	0101	2
00:51:16	00:00:46	2	105	192	170	150	191	128	46	405	0	0101	2
00:51:68	00:00:52	2	107	198	173	149	188	130	52	404	0	0101	2
00:52:24	00:00:56	2	105	202	175	149	189	130	55	410	0	0101	2
00:52:78	00:00:54	2	104	196	179	156	187	127	57	415	0	0101	2
00:53:28	00:00:50	2	96	184	173	148	179	128	48	406	0	0101	2
00:53:78	00:00:50	2	98	200	179	150	184	127	51	419	0	0101	2
00:54:24	00:00:46	2	93	199	178	149	180	123	47	412	0	0101	2
00:54:72	00:00:48	2	85	186	171	144	170	121	47	394	0	0101	2
00:55:20	00:00:48	2	91	186	173	148	173	123	49	414	0	0101	2
00:55:66	00:00:46	2	88	181	172	148	169	122	47	407	0	0101	2
00:56:14	00:00:48	2	89	180	171	148	164	122	50	397	0	0101	2
00:56:62	00:00:48	2	84	179	171	150	159	126	50	406	0	0101	2
00:57:10	00:00:48	2	94	184	179	156	172	128	54	433	0	0101	2
00:57:58	00:00:48	2	100	183	177	155	172	134	52	440	0	0101	2
00:58:06	00:00:48	2	109	181	177	158	177	133	54	451	0	0101	2
00:58:54	00:00:48	2	121	181	176	161	179	133	51	465	0	0101	2
00:59:02	00:00:48	2	124	178	175	168	180	128	53	451	0	0101	2
00:59:50	00:00:48	2	127	179	174	177	182	133	54	463	0	0101	2
00:59:98	00:00:48	2	127	178	175	179	182	131	52	471	0	0101	2
01:00:44	00:00:46	2	128	179	173	191	189	133	52	482	0	0101	2
01:00:92	00:00:48	2	130	178	173	189	184	132	51	482	0	0101	2
01:01:40	00:00:48	2	126	177	168	183	196	131	51	477	0	0101	2
01:01:86	00:00:46	2	129	178	172	201	188	137	49	483	0	0101	2
01:02:34	00:00:48	2	128	181	173	204	189	134	49	482	0	0101	2
01:02:82	00:00:48	2	126	182	178	224	199	137	49	505	0	0101	2
01:03:30	00:00:48	2	126	182	173	211	191	138	53	482	0	0101	2
01:03:78	00:00:48	2	124	193	181	226	199	137	55	513	0	0101	2
01:04:24	00:00:46	2	122	197	180	207	202	136	54	518	0	0101	2
01:04:70	00:00:46	2	123	187	180	210	190	136	52	482	0	0101	2
01:05:20	00:00:50	2	120	184	182	216	190	137	48	487	0	0101	2
01:05:74	00:00:54	2	121	183	182	210	179	136	50	486	0	0101	2
01:06:26	00:00:52	2	120	185	183	215	182	140	49	495	0	0101	2
01:06:74	00:00:48	2	119	187	182	209	172	139	51	501	0	0101	2
01:07:22	00:00:48	2	124	191	177	180	177	139	50	490	0	0101	2
01:07:70	00:00:48	2	129	198	176	208	179	149	54	490	0	0101	2
01:08:18	00:00:48	2	126	215	186	230	202	152	56	530	0	0101	2
01:08:70	00:00:52	2	126	219	187	223	204	155	54	539	0	0101	2
01:09:20	00:00:50	2	126	235	191	230	214	150	51	552	0	0101	2
01:09:68	00:00:48	2	128	223	179	198	208	150	50	528	0	0101	2

AREA OF WEAK BOND

Figure 12 Computer Analysis of Rejected Roadwheel

Such an evaluation, if performed over a sufficiently large number of acceptable and rejectable roadwheels, will allow verification of this test's ability to predict peel test results. This will establish basic criteria for testing.

7.2 Drum Test

Two wheels, which were to be drum tested, were ultrasonically inspected and the data were recorded for later analysis. Computer data, typical of these wheels, is shown in Figure 13. They show very little variation around the circumference of the wheel - indicating a wheel which might be expected to pass a subsequent drum test.

Both wheels passed the 48 hour drum test, giving hope that the ultrasonic test might be a measure of subsequent drum performance. Again, not enough data is available to verify the validity of the inspection approach.

7.3 Frequency/Deviation Analysis

The peel and drum test results presented above are based upon subjective analyses of the presence or absence of localized ultrasonic signal variations. GARD also performed a computerized analysis of averaged signals around wheel circumference to determine how they relate to wheel classification.

Figure 14 is a summary of computer generated data, the signal provides a signal average, and standard deviation information for each frequency channel of inspected wheels. It shows data from 4 wheels: two wheels from the acceptable production lot, and two wheels from two marginal RRAD production lots. The former were subsequently road tested; the latter were peel tested and had about 60% "good" and 40% "understrength" bond. The signal illustrates typical ultrasonic signal distributions from bondline areas of accepted, and from good and bad bondline areas of marginal lots.

Three trends can be noted in the graph. First, it may be possible to separate "acceptable" roadwheel lots from "rejectable" roadwheel lots by appropriate alarm condition setting, in this case in the 110 or the 500 kHz frequency channels. (Interestingly, the "acceptable" signals are higher in one channel and lower in the other. This effect has not been analyzed.)

08 RW19, M97, ODB: 0-5RDC/64 - FGW PASS 2 46

TIME	INTERVAL	RDC	110	150	200	270	370	500	675	920	LOC	AOCF	KE
00:02:04	00:02:04	0	0	0	0	0	0	0	0	0	0	0000	2
00:17:76	00:15:72	0	14	52	46	43	59	46	19	103	0	0101	2
00:18:22	00:00:46	2	70	268	175	195	269	199	77	485	0	0101	2
00:18:74	00:00:52	2	53	210	178	195	258	189	69	443	0	0101	2
00:19:20	00:00:46	2	60	228	178	200	260	193	68	458	0	0101	2
00:19:72	00:00:52	2	55	253	176	200	257	196	71	479	0	0101	2
00:20:24	00:00:52	2	44	221	148	174	205	176	64	409	0	0101	2
00:20:80	00:00:56	2	56	227	145	184	207	181	60	428	0	0101	2
00:21:40	00:00:60	2	94	274	134	158	183	148	66	375	0	0101	2
00:22:06	00:00:66	2	109	270	166	199	241	183	86	461	0	0101	2
00:22:60	00:00:54	2	103	212	140	182	231	171	55	426	0	1101	2
00:23:10	00:00:50	2	108	228	159	218	268	196	60	485	0	0101	2
00:23:58	00:00:48	2	100	200	157	209	274	199	50	483	0	0101	2
00:24:08	00:00:50	2	101	207	159	194	273	201	54	486	0	0101	2
00:24:60	00:00:52	2	99	210	157	210	273	199	51	485	0	0101	2
00:25:08	00:00:48	2	97	214	146	198	249	185	48	429	0	0101	2
00:25:60	00:00:52	2	104	208	156	202	271	195	54	482	0	0101	2
00:26:08	00:00:48	2	102	210	161	204	280	203	57	487	0	0101	2
00:26:56	00:00:48	2	94	206	161	196	270	197	52	484	0	0101	2
00:27:06	00:00:50	2	91	208	167	200	274	201	59	492	0	0101	2
00:27:56	00:00:50	2	74	210	166	205	274	200	60	498	0	0101	2
00:28:06	00:00:50	2	73	201	166	205	275	203	59	481	0	0101	2
00:28:56	00:00:50	2	56	213	167	206	270	201	57	488	0	0101	2
00:29:04	00:00:48	2	47	202	169	202	266	198	57	469	0	0101	2
00:29:56	00:00:52	2	38	218	167	198	267	199	57	475	0	0101	2
00:30:04	00:00:48	2	33	217	165	200	260	197	61	464	0	0101	2
00:30:54	00:00:50	2	36	229	175	200	254	195	59	466	0	0101	2
00:31:04	00:00:50	2	36	227	175	195	244	191	64	457	0	0101	2
00:31:52	00:00:48	2	39	227	178	198	234	190	59	456	0	0101	2
00:32:02	00:00:50	2	52	228	177	190	242	184	67	440	0	0101	2
00:32:48	00:00:46	2	60	221	179	191	246	183	70	433	0	0101	2
00:33:00	00:00:52	2	68	205	184	198	253	187	74	438	0	0101	2
00:33:48	00:00:48	2	64	203	192	190	255	183	84	444	0	0101	2
00:33:96	00:00:48	2	47	195	191	177	247	182	83	429	0	0101	2
00:34:46	00:00:50	2	42	191	187	183	247	184	71	417	0	0101	2
00:34:94	00:00:48	2	55	190	172	175	232	182	59	396	0	0101	2
00:35:44	00:00:50	2	56	186	180	178	229	178	59	410	0	0101	2
00:35:92	00:00:48	2	68	198	200	194	254	191	66	456	0	0101	2
00:36:44	00:00:52	2	56	203	197	192	252	191	70	455	0	0101	2
00:36:92	00:00:48	2	45	202	198	193	251	193	69	450	0	0101	2
00:37:46	00:00:54	2	44	199	197	192	250	192	76	453	0	0101	2
00:37:90	00:00:44	2	45	190	189	182	244	187	77	432	0	0101	2
00:38:38	00:00:48	2	41	190	181	183	243	186	81	418	0	0101	2
00:38:88	00:00:50	2	39	208	191	201	257	193	91	462	0	0101	2
00:39:38	00:00:50	2	40	203	191	199	257	193	91	450	0	0101	2
00:39:88	00:00:50	2	46	199	184	190	251	188	84	444	0	0101	2
00:40:76	00:00:88	0	0	0	0	0	0	0	0	0	0	0000	E

Figure 13 Computer Analysis From Accepted Roadwheel

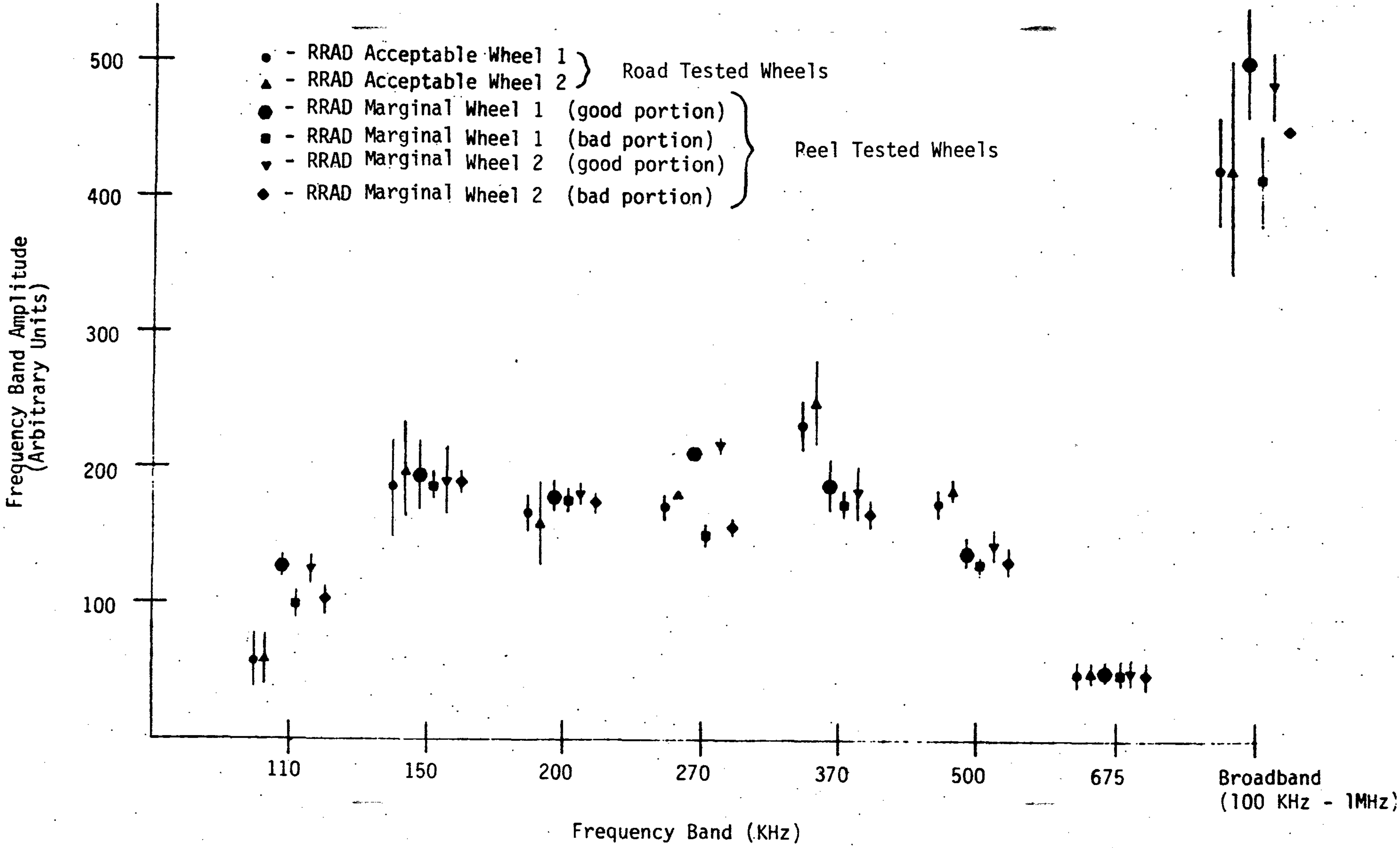


Figure 14 Ultrasonic Frequency Distribution for Acceptable and Marginal Roadwheels

Second, weak bond and strong bond area signals, on an individual wheel, may be separable on the 110 kHz, 270 kHz, and the broadband frequency channels. Third, signal separation of weak bond vs. strong bonds on an absolute basis (i.e., on any wheel out of any production lot) is not clear.

Similar data comparisons on other wheels in our limited data base gave similar results: no clear distinction between the wheels and their subsequent peel, drum and road results when comparisons were made based upon circumferentially-related amplitude-dependent ultrasonic results.

As the next section shows a different, localized measure was needed to show some correlation with road test results (as was already shown to be the case for drum and peel test correlation).

7.4 Road Test

This Section discusses ultrasonic data correlation with road test results. This analysis is done in two steps: a) roadwheel road test results are presented, and then b) accept/reject criteria indicative of road test results are established by post-test analysis of the pre-test recorded ultrasonic data to measure potential feasibility of ultrasonic road test result prediction.

Figure 15 provides the results of field disposition of each of the 18 roadwheels which were sent out to be field tested. Key items presented are total mileage on each roadwheel, and comments by field personnel relative to test completion of each wheel. Two notes must be made regarding this information:

- The analysis which follows is based upon the provided field comments. There was no engineering follow-up to determine the validity of failure mode identified by field personnel.
- Each wheel completed its required life cycle of 2000 miles, Thus, in truth, no wheel "failed". A second road test was performed on these same wheels (starting after 2021 miles). It was during this second road test that some of the wheels failed. Thus the ultrasonic correlation analysis below can only an attempt to show that ultrasonics can grade potential roadwheel performance - not that it can predict failure

Marginally Acceptable Lots

GARD #	MILEAGE	FIELD COMMENTS
14	2,021	
6	2,021	SN ID lost after this point;
15	2,021	1 wheel "lost"; other 3 went 3,389-4,724 miles; chunking
12	2,021	ended testing
10	5,260	completed test successfully
9	4,724	Damaged; stopped testing
7	5,058	Wear plate wore out; stopped testing
3	3,726	debonded; stopped testing
8	3,726	debonded; stopped testing
2	3,014	debonded; stopped testing
4	4,482	chunked; stopped testing
5	4,245	chunked; stopped testing

Acceptable Lot

GARD #	MILEAGE	FIELD COMMENTS
18	5,260	completed test successfully
19	4,981	chunked (with 7 other roadwheels); stopped testing
20	5,058	Wear plate wore out; stopped testing
23	2,127	debonded; stopped testing
21	3,731	chunked; stopped testing
22	3,098	debonded; stopped testing

Figure 15 Road Test Results

(since no roadwheels technically "failed" in terms of strict definition).

The combinations of mileage and field comments were used to define the roadwheel data base for use in subsequent analysis. All the wheels and their given mileage/disposition were included in the analysis, other than as indicated below:

- wheels 14, 6, 15, and 12 were excluded totally. After 2021 miles (the first road test), one wheel was "lost"; the other 3 went additional miles before removal due to chunking. There was no serial number identification to tell which was lost or which 3 ran and chunked. There was not way to do ultrasonic correlation with respect to these wheels.
- Wheel 19 final mileage was taken to be 5,260 miles. It chunked with 7 other wheels (which were not part of this test) at 4,981 miles. We assume this was not a roadwheel caused failure. Excessive wear was not reported for the wheel, thus we assumed this wheel could have successfully completed the second road test at 5,260 miles, if it had been allowed.
- Wheels 7 and 20 were taken to be 5,260 miles. They sustained aluminum wheel wear with no rubber damage at 5,050 miles. Excessive rubber wear was not reported for these wheels, thus we assume these wheels would have successfully completed the second road test at 5,260 miles, if they had been allowed.
- Wheel 9 was taken off test after a suspension road arm spindle bearing lock nut came loose. It elongated the mounting stud holes and chunked the rubber. Since 4,724 miles were accumulated without problem prior to this incident it is assumed that the wheel would have successfully completed the second road test at 5,260 miles, if it had been allowed.

The result and data base for ultrasonic correlation are shown in Figure 16.

Both the Marginally Acceptable and Acceptable lots fall into 3 disposition modes: debonded, chunked, and completed test (as a function of mileage). Philosophically, this can make sense. First, we had a vehicle test which lasted

Marginally Acceptable Lots

GARD #	MILEAGE	COMMENTS
10	5,260	completed test successfully
9	5,260	completed test successfully
7	5,260	completed test successfully
3	3,726	debonded; stopped testing
8	3,726	debonded; stopped testing
2	3,014	debonded; stopped testing
4	4,482	chunked; stopped testing
5	4,285	chunked; stopped testing

Acceptable Lot

GARD #	MILEAGE	COMMENTS
18	5,260	completed test successfully
19	5,260	completed test successfully
20	5,260	completed test successfully
21	3,731	chunked; stopped testing
22	3,099	debonded; stopped testing
23	2,127	debonded; stopped testing

Figure 16 Roadwheel Road Test Data Base

2,021 miles. All the wheels survived; the vehicle experienced no mechanical problems. On the second vehicle test, wheel and mechanical problems showed up. Early failures, after test start, were due to weak bondlines reaching the end of the useful life; then mechanical problems in the track system surfaced causing chunking; the wheels which survived the above continued to run.

We assume individual mileage number for this small sample lots is statistical scatter. Thus, we can use average mileage identifiers:

Observed Disposition	MA Lots Mileage	A Lot Mileage	Averaged Mileage	Defined Disposition
Debonded	3489 (3)	2613 (2)	3339	Failure
Chunked	4384 (2)	3731 (1)	4166	Non-Failure
Running	5260 (3)	5260 (3)	5260	Non-Failure

We define debonding as a roadwheel-related failure and chunking as a vehicle-related problem. For purposes of the following analysis we classify chunking with test completion (running) as non-failures.

The question is: can ultrasonics, as used to inspect the roadwheels on this program, separate the failed (debonded) roadwheels from the non-failed roadwheels? It is understood that based upon limited sample size, and post-test analysis, any result can only be an indication of potential technique capability: particularly since no roadwheel technically failed the road test in terms of mileage.

7.5 Ultrasonic Data Analysis

The data accumulated on roadwheels include measures of both signal amplitude and phase. As the discussion in Section 4.3 indicates, expectation was minimal that an analysis based upon the circumferentially averaged information would be fruitful. Figure 17 shows: A (average signal amplitude) and σ (standard deviation) in the broadband mode for all three inspection passes, for each of the 14 roadwheels. Similar results were observed in the narrow-band frequency channels. No significant signal variation between "failed" and "passed" wheels could be discerned in this averaged data.

		CHANNEL No. 1 Inside		CHANNEL No. 2 Midline		CHANNEL No. 3 Outside	
GARD RW#	Disposition	A[2]	σ[3]	A	σ	A	σ
	PASSED						
7	R	594	75	528	70	504	85
20	R	441	49	409	50	433	46
10	R	520	53	514	53	545	47
18	R	585	63	541	42	588	58
19	R	488	45	453	46	483	35
9	R	582	44	512	50	553	50
21	C	438	50	445	37	433	52
5	C	548	59	537	45	554	73
4	C	487	69	517	53	537	56
	FAILED						
22	D	511	35	490	35	506	42
2	D	548	44	533	38	546	77
8	D	485	63	432	67	494	76
3	D	574	53	506	49	484	52
23	D	466	55	480	45	517	40

1 D = Debond, C = Chunked, R = Completed Test

2 A = Average signal amplitude around roadwheel circumference

3 σ = Standard deviation of A

Figure 17 UT Data Analysis with Average and Standard Deviations

Other data analysis approaches, based upon localized signal changes, were considered in an attempt to find some measure of ultrasonic/road test correlation. After reviewing the printout listings of circumferential data, for all three passes, for all 23 wheels (i.e., data such as shown in Figure 13), we came up with 2 measures of interest:

ΔA = Maximum signal amplitude - minimum signal amplitude, in the broadband signal channel; minimum signal amplitude is defined as one which has an adjacent signal within 50 digits of itself (this eliminates small area dropouts, hypothesized as not representative of failure inducing causes)

%DB = percentage of circumferential area which is indicated as debonded.

This data, when calculated, gave the results shown in Figure 18. An analysis of these results shows that the presence of a large ΔA (≥ 200) and/or a large % debond ($\geq$ 10%) for any of these wheels provides a reasonable indication of debonding. See Figure 19 . This Figure also provides the ultrasonic results for the 3 peel tested wheels in the same format. (The 2 steel wheels which were drum tested cannot be presented in this format because the bondline interface provides a different reflection signal level vs. all the other aluminum wheels. The 2 wheels, both passed, do not provide enough data for any type of relative analysis.

Using the post-test established criteria that wheels with $\Delta A \geq 200$ and/or % debond $\geq$ 10 should behave worse (i.e., fail vs. pass) than those which do not have such a large bondline variation, we can say the following:

- ultrasonics correctly identified 4 of 5 wheels which failed at the expense of 1 good wheel called rejectable,
- the peel test correctly identified 3 of 5 wheels which failed at the expense of 5 good wheels called marginal,
- ultrasonics made 12 of 14 correct calls in terms of field results (4 of 5 failures and 8 of 9 passes), and
- the peel test made 7 of 14 correct calls in terms of field results (4 of 6 acceptable wheels passed; 3 of 8 marginal wheels failed).

GARD RW#	DISPOSITION	CHANNEL No. 1 Inside ΔA	CHANNEL No. 1 Inside % Debond	CHANNEL No. 2 Midline ΔA	CHANNEL No. 2 Midline % Debond	CHANNEL No. 3 Outside ΔA	CHANNEL No. 3 Outside % Debond
	PASSED						
7	R	120	0	170	0	190	4
20	R	161	0	196	0	150	0
10	R	181	0	172	0	188	3
18	R	90	29	122	42	168	48
19	R	97	0	139	5	158	2
9	R	43	0	105	0	120	0
21	C	187	0	145	0	97	0
5	C	164	5	144	0	118	0
4	C	190	0	132	0	147	0
	FAILED						
22	D	84	0	114	0	112	0
2	D	121	2	121	10	77	13
8	D	330	0	207	0	243	0
3	D	97	0	248	47	200	100
23	D	277	0	172	0	109	0

1 D = Debond, C = Chunked, R = Completed Test

Figure 18 UT Data Analysis with Change in Amplitude and Phase

GARD RW#	DISPOSITION	CHANNEL No.1 Δ A	CHANNEL No.2 Δ A	CHANNEL No.3 Δ A	CHANNEL No. 1 %Debond	CHANNEL No.2 %Debond	CHANNEL No.3 %Debond	RRAD LOT DESIGNATION
ROADTEST								
7	Passed	120	170	190	0	0	4	MA
20	Passed	161	196	150	0	0	0	A
10	Passed	181	172	188	0	0	3	MA
18	Passed	90	122	168	29	42	48	A
19	Passed	97	139	158	0	5	2	A
9	Passed	43	105	120	0	0	0	MA
21	Passed	187	145	97	0	0	0	A
5	Passed	164	144	118	5	0	0	MA
4	Passed	190	132	147	0	0	0	MA
22	Failed	84	114	112	0	0	0	A
2	Failed	121	121	77	2	10	13	MA
8	Failed	330	207	243	0	0	0	MA
3	Failed	97	248	200	0	47	100	MA
23	Failed	277	172	109	0	0	0	A
PEEL TEST								
1	"Failed"	102	135	311	11	0	20	
11	"Failed"	245	217	274	0	1	75	
13	"Failed"	116	145	109	3	3	19	

* UT Fail: $\Delta A \geq 200$; $\%DB \geq 10$

Figure 19 UT Pass/Fail Analysis *

7.6 Discussion

Several constraints on our data analysis should be restated:

- final field disposition of each roadwheel was unconfirmed. There was no engineering follow-up to verify final wheel state (i.e., debond vs. chunk, etc.),
- no technical failures occurred in the wheels (the "failure" which occurred were all after the required 2000 mile life),
- the "marginally acceptable" lots were lots which by choice, RRAD rejected for field use. This choice can be considered unnecessary per Figure 19 since there is no real performance difference between the acceptable and the marginally acceptable lots (debond failures were 33% vs. 38% respectively), if we consider all the wheels passed the 2000 mile test,
- our sample size cannot give us much confidence in the absoluteness of the ultrasonic correlations.

Within this framework, we state the following:

- ultrasonics did a fairly good job of identifying "bad" wheels (80%), and making correct field calls (86%),
- peel test identification of "bad" wheels was 60%, but for correct field calls it was only 50% accurate.

Feasibility of using ultrasonics to evaluate roadwheel bondline quality has been established - within project constraints of sample size, etc.. The results achieved relative to peel test results bring two questions to mind: a) can ultrasonics replace the peel test in production quality control applications, and b) can ultrasonics (since it can be so configured) be used as a field inspection tool for on-vehicle quality monitoring? Specific questions such as whether the selected accept/reject limits are valid, and why percent debond and amplitude variation do not track on individual wheels (as might be intuitively expected) remain to be determined.

These questions can only be answered by acquisition and engineering evaluation of a large amount of data, both for ultrasonic peel test, and for ultrasonics vs. road test. The former is being evaluated in a TACOM engineering analysis project correlating ultrasonic data (acquired from a microprocessor-based production-line ultrasonic Roadwheel Inspector, developed by GARD for TACOM under Contract No. DAAE07-81-C-4030) and subsequent RRAD peel tests, on a planned lot of 1000 roadwheels.

The ultrasonics vs. road test correlation will require a similar effort. However, problems demonstrated in the current project (trying to road test pre-inspected roadwheels - it took 3 years to complete) require a different approach to testing: planned high mileage vehicles with mounted new roadwheels should be identified; field base-line ultrasonic inspection should be performed on the mounted wheels; the wheels should then be followed through to final disposition; then data analysis performed.

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