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Evaluation of Central Tire Inflation Internal Drive Axle Seals

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Central Tire Inflation

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BACKGROUND

There is a Service-wide desire to see the use of central tire inflation/variable tire pressure (CTI/VTP) on heavy vehicles that traverse Forest Service roads. Efforts conducted by the San Dimas Technology and Development Center (SDTDC) have shown that CTI/VTP technology offers obvious benefits with regard to road maintenance and in many cases, will even repair damaged roads. There are also user benefits such as better traction, reduced impact to both suspension and drive train, reduced driver fatigue, and possibly fewer instances of tire damage resulting from sharp objects.

The Forest Service and the logging industry should mutually benefit from the use of this technology, yet—for several reasons—it has been difficult to sell the idea to loggers. Ranking high as an issue of concern among prospective users is the outboard drive tire supply hose used on early prototype CTI systems. This VTP approach has been used successfully on many trucks without any hose-related problems, and it remains the least expensive approach to controlling the drive tire pressure. Still, few truck owners want to see these vulnerable-looking hoses dangling outside their trucks, and this is somewhat understandable. Therefore, in an effort to gain user acceptance and promote the use of CTI/VTP, a prototype internal drive axle seal was developed to eliminate the need for san outboard supply hose.

INTRODUCTION

In mid-February 1990, a set of engineering model rotary air seals were installed on the drive axles of an 80,000-lb GCW (gross combination weight), 18-wheel, Forest Service test vehicle. This vehicle—originally a 10-yd dump truck—was converted to a western style logging truck configuration. The seals were designed to allow compressed airflow to and from the drive tires while the truck is in motion. These "internal drive axle seals" (IDAS) are used as components in a contemporary CTI system. This report is an account of events and circumstances recorded during 7,600 miles of IDAS testing, during the monitoring of seal performance, in an effort to evaluate the design and predict the mean-time-to-failure of these seals. Another objective of the tests was to display and demonstrate this technology to prospective users, with the hope of improving their willingness to accept this technology.

TEST PROGRAM

Objective

The purpose of the IDAS test program was to gather technical experience which could assist SDTDC in writing standards and specifications for future systems and to contribute to state-of-the-art advancement in CTI. Design criteria stated that the combined leakage rate of four IDAS could not exceed 2 standard cubic feet per minute (scfm). Individual seals could not leak at a rate greater than 1/2 scfm.

Procedure

A 10,000-mile test was planned to continuously monitor seal performance under various conditions of pressure; speed; temperature; load and road type; upgrade, level, and downgrade under heavy braking for extended periods. A detailed description of the test procedure is included in appendix 1.

Test data collected include continuous written and strip chart records of the aforementioned conditions as they occurred during the test. Only 7,600 miles have been logged with these seals in place. However, it is apparent that no further testing is really necessary since we don't yet notice any trend indicating that seal performance deteriorates relative to mileage, and it is doubtful that another 2,400 miles would clearly delineate this for the purpose of predicting the mean-time-to-failure. Appendix 2 presents the test itinerary, static leakage test results, pressurized hub times, and calibration data.

Results

Figure 1 presents leakage rates that have been calculated from data recorded during the tests. As shown, the collective leakage rate for all four seals ranged from 0.02 to 4.09 scfm, and averaged 0.56 scfm throughout the test period. The most severe leak, 4.09 scfm, was far from normal, as the second most severe leak was only 0.74 scfm. Actually, the severe leak was recorded during a static leakage test on February 20, 1990 (data No. 049—see appendix 2), when the hub temperature was approximately 30 °F and the truck had been stationary for over 12 hours. After the seals warmed up for a few minutes, the leakage was negligible. It appears that seal leakage is more sensitive to hub temperature than wear. No direct correlation between seal performance and distance travelled can be drawn.

DISCUSSION

TISCO, a small, local (Pomona, CA) company working in the CTI field, determined that if the seal housing temperatures remained below 250 °F, lip seal life would not diminish. The highest temperature reached during this test was only 200 °F. This peak temperature was recorded while descending a 6 percent downgrade, fully loaded, for approximately 26 miles. Heavy braking was required on this portion of the highway (I-5) to maintain a safe speed. It

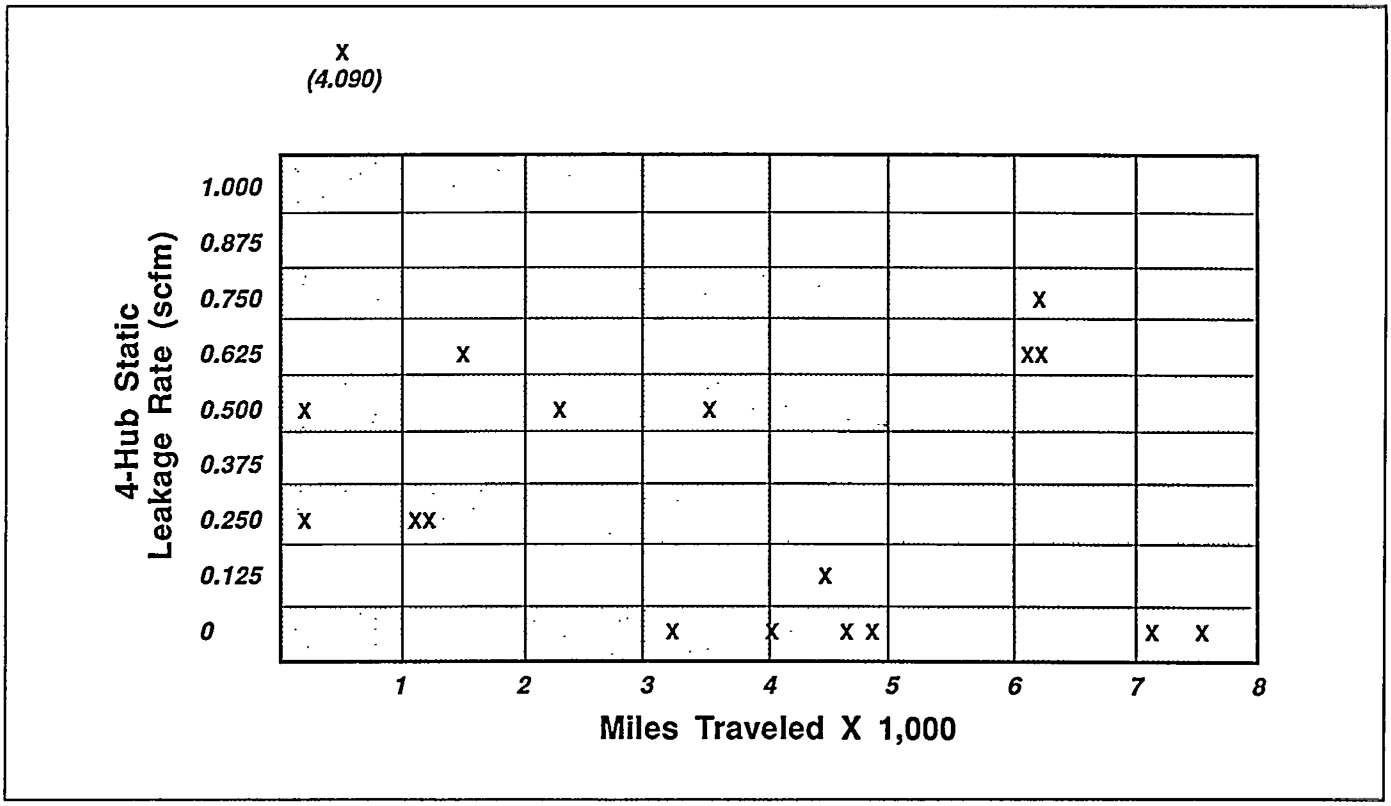

Figure 1. Leakage rates as a function of miles traveled.

is doubtful that one would encounter conditions that would generate more heat than this in the hub area.

The original test plan (appendix 1) suggested that test results could be used to predict the operating cost per vehicle that might be expected if seal kits were produced on a large scale. That prediction is beyond the scope of this test, particularly if one was to consider using the seal in a continuous application. Until sufficient quantities are required to justify automated manufacture, each seal kit might cost approximately $1,500 for materials and labor to machine, treat, and install on a custom basis. If the seal life is similar to a grease seal, then it should be replaced whenever the brake linings are changed. If this maintenance interval occurs at 60,000 miles, the cost of the first set would be around 10 cents per mile. If a seal replacement kit that would service four axle ends costs $600, subsequent servicing would cost a penny per mile. These estimates are very crude, and are based on very few facts. At this point, it appears that 60,000 miles could be attainable if the seals are operated on an intermittent basis.

CONCLUSIONS

The test program results lead to the following conclusions:

- The seals operated satisfactorily without any maintenance problems and their use did not contribute to the failure of any existing truck components.

- Heat buildup in the lip seal housing reached 200 °F, but did not adversely impact on seal performance or life expectancy in this test.

- Since seal performance hasn't noticeably deteriorated during the short test period, there are insufficient data to predict mean-time-to-failure when operated on a continuous basis. Operated intermittently, as in this test, a very satisfactory life can be anticipated.

- The torque required to overcome axle end friction (approximately 2 ft-lb) did not change in any measurable way throughout the course of this test.

RECOMMENDATIONS

Do not invest further resources in the development of this particular seal design. Since these seals were installed, TISCO has developed a cartridge-type rotary air seal which replaces the existing oil seal. These seals are now being tested in Ohio on sanitation vehicles that operate under severe service conditions. If this design proves to be reliable, it would likely render the radial lip seal obsolete for the following reasons:

• It involves less effort and expertise to install and maintain; and, consequently, less cost to the truck owner.

• Bearings remain lubricated by the differential oil—some have expressed concern about this—and the air does not pass through the bearings, thereby eliminating the potential for damaging lubricant getting into the tires.

• Seal repair kits should be very inexpensive, compared to the radial lip seal, since they would consist of only two O-rings.

APPENDIX 1— PRELIMINARY TEST PLAN

Prepared by LaMoure Besse, SDTDC Mechanical Engineer

ROTARY SEALS FOR DRIVE AXLES— ENGINEERING TEST MODEL

BACKGROUND: Several months ago, TISCO [Tire Inflation Systems Corp.], Pomona, CA, approached the Forest Service at their San Dimas Technology and Development Center with an offer to install radial seals on a surplus Forest Service dump truck near their corporate facilities if, in return, they could demonstrate the seals to visitors and have the Forest Service spend a small amount of time testing the seals. The primary motivation for TISCO was the fact that concurrently they were bidding on a U.S. Marine contract to develop and supply 5,000 retrofit CTI kits. TISCO was considering commercializing the kit, which would feature a similar seal that could be used on hauling trucks.

One of the principals in TISCO is Joe Bartos. Based on our continuing desire to find sources for drive axle seals, Joe agreed to provide us with the set of seals he had begun to design for the Forest Service dump truck, and installation was completed in January 1990. The dump truck rear axle assembly was dismantled and measurements were taken by TISCO for the purpose of having dimensional accuracy in designing the seal. The Marine Corps opened bids for ten prototype systems and selected another bidder. This event reduced TISCO's desire to develop a commercial kit because of less opportunity to amortize the development cost over other projects.

GOALS AND OBJECTIVES: This test reflects a Sevice-wide desire to see broad-scale national use of CTI. With the technical knowledge gathered from this test, the Forest Service will be better prepared to write specifications and standards for future systems.

The objective is to monitor seal performance for 10,000 miles on- and off-highway to learn about performance and maintenance features, to measure heat buildup and leakage rate, and to predict the mean-time-to-failure of these rotary seals in this application.

TEST APPARATUS: On-highway, the seals will be tested at 90 psig cold tire pressure (ambient); off-highway, the seals will be tested between 25 and 60 psig. Mileage on the truck will be obtained as much as practical from actual operating conditions. In an effort to attain these conditions, the truck will be used to support off-highway testing in Idaho, and travel from Southern California to Idaho and back and to two logging conferences to simulate on-highway operation. Additional testing will be performed as needed on a SDTDC test bench to attain sufficient mileage.

TEST PROCEDURE:

A. *DRIVE TIRE PRESSURE*—A chart recorder shall be installed on the truck to record, on a continuous basis, the tire pressure in the drive tires. The recorder shall be monitored by a technician to ensure continuous operations. Periods when the wheel valves are closed shall be the only time the recorder is shut down. Correlation with other parameters on a common time base shall be maintained.

B. *SEAL TEMPERATURE*—Thermocouples mounted on the inside seal housing shall be monitored on a continuous basis and correlated with the data above. Calibration of the thermocouples will be completed at the end of testing because access to the ends for inducing temperature variation is restricted.

C. *TRAVEL SPEED*—A chart recorder shall also record, on a continuous basis, the velocity of the vehicle and the total distance travelled shall be recorded to the nearest 10th of a mile on an odometer.

D. *LEAKAGE RATE*—Each axle end shall be identified separately, and a log sheet shall be maintained for each. General information such as date, odometer reading, etc. shall be recorded on the designed log sheet.

1. Immediately prior to operating any axle end, after the tires are mounted and all hoses are connected between the valve stem and the main line from the inflate/deflate valve, each seal shall be tested for leakage by closing the tire valves on all but one seal and recording the rate at which the pressure in the static tank falls. This shall be repeated three times or more if results do not prove to be consistent when plotted on graph paper.

2. This test shall be repeated after rotating the wheels off the ground for a short period of time (1 minute, or so) and at low rpm.

3. Then the truck should be driven around the facility at city speeds for 1/2 hour empty and retested.

4. Then the truck shall be operated empty on-highway in this vicinity for 1/2 hour and retested.

5. Then the truck shall be driven to Oregon and retested before leaving, half way there, and after arriving.

6. Then the test shall be repeated every week until a significant difference is found in leakage.

In cooperation with Leonard Della-Moretta, Program Leader for Special Projects, and a student aide, the volume of the two tires, hoses, seal, and static tank shall be measured to use as a reference for calculating the rate at which free air leaks from each seal. This measurement should be made at the axle end which has the tightest seal. The volumes determined from this procedure, along with appropriate calculations, shall be recorded in the log book.

E. *TORQUE*—Using the instrumentation installed for gradeability testing on the drive shaft, measure the torque on the drive shaft with the tires off the ground at low and high pressure. Perform this test prior to operating the vehicle and approximately once each month. The data recorded shall be graphed to show the static and dynamic torques and their difference as a function of tire pressure and ambient temperature.

F. *LOG BOOK*—A general log book shall be maintained and the operator of the truck shall record, on a daily and/or event basis, all pertinent information that might be of value later in analyzing test results. Installation comments shall be located on the first pages of the book and shall highlight the installation process and its problems, complexities, and good features. Times for installation shall be approximated. Weather conditions, road conditions, vehicle loadings, etc. might be examples of information to be found in the diary along with travel routes, people visited, etc. Diary information should be maximized rather than minimized.

G. *TROUBLE SHOOTING, MAINTENANCE AND REPAIRS*—At any point in this test where a significant event occurs, Joe Bartos and LaMoure Besse shall be notified. No disassembly of the axle, hub, brakes, or any connection between the tire valve stems and the fittings that attach to the outside of the brake shall occur without Joe Bartos and LaMoure Besse present.

TEST RESULTS: Test results will include a table of positive and negative features of the rotary face seal, and a table outlining maintenance required—with comments. Comments on installation, including approximate times and complexity, will also be presented.

A curve will be plotted showing leakage rates and how they changed over time. Travel times at various speeds will be averaged and recorded. Mean-time-to-failure and operating costs per mile will be approximated based on the assumption that the seals are produced in substantial quantities. The merits of this type of seal being used with a system that has intermittent service and wheel valves will be commented on and compared to systems featuring continuous operation.

APPENDIX 2—TEST DATA

ITINERARY

Date	*From*	*To*	*Comments*
2/19/90	SDTDC	Santa Rosa, CA	Some static leakage after cooling
2/20/90	Santa Rosa, CA	Roseburg, OR	Worst record.leak, static, temp ~30 °F
2/21/90	Roseburg, OR	Eugene, OR	Attend logging conference
2/24/90	Eugene, OR	Yreka, CA	
2/25/90	Yreka, CA	Lakeport, CA	3-hr static (data No. 066-068)
2/25/90	Lakeport, CA	Upperlake, CA	Minor, non-CTI repairs
2/27/90	Upperlake, CA	Santa Rosa, CA	Load logs (78,750 GCW) in Calpella LP
2/28/90	Santa Rosa, CA	Dublin, CA	Left steer swivel unscrewed flat tire
3/01/90	Dublin, CA	SDTDC	Peak temp 200 °F on 6% downgrade
3/08/90	SDTDC	Yucaipa, CA	Odometer check against van No. 721
3/11/90	SDTDC	Santa Rosa, CA	
3/12/90	Santa Rosa, CA	Upperlake, CA	Rd hzrd., No.10-32 screw, 2 flat (RRT)
3/13/90	Upperlake, CA	Ukiah, CA	Unloaded logs; attended conference
3/19/90	Ukiah, CA	Cotati, CA	Rpm data recorder problems
3/20/90	Cotati, CA	Upperlake, CA	Return; attempt to get lg. diam. logs
3/20/90	Upperlake, CA	Cotati, CA	Unsuccessful at log procurement
3/21/90	Cotati, CA	SDTDC	Rpm channel revived
6/08/90	SDTDC	Auburn, CA	Long static, 3.5 hr (data No. 198)
6/10/90	Auburn, CA	Winnemucca, NV	
6/11/90	Winnemucca, NV	Caldwell, ID	
6/12/90	Caldwell, ID	Moscow, ID	Pressurized (data No. 215-217)
6/13/90	Moscow, ID	(Local)	Sediment tests
6/19/90	Moscow, ID	Parma, ID	Display, FS Sciences Lab, Moscow, ID
6/20/90	Parma, ID	Lovelock, NV	
6/21/90	Lovelock, NV	Reno, NV	Leave in Reno for display/demo
6/26/90	Reno, NV	Auburn, CA	
6/27/90	Auburn, CA	SDTDC	

STATIC LEAKAGE TESTS

Data No.	*Hub ID*	*Hub temp (°F)*	*P1—P2 (psi)*	*Time (min)*	*Flow (scfm)*	*Comments*
005	RFD	—	90 -	26	—	Leaking hose
006	RFD	—	90 - 65	60	0.24	
009	RRD	—	87 - 4	60	—	No seal ring
012	LFD	—	89 - 60	60 x 16	0.017	
013	RRD	—	89 - 85	100	0.023	
014	LRD	—	90 - 51	60	0.38	Brake flange leak
026	All 4	>100	83 - 73	80	0.29	
032	All 4	<100	90 - 70	90	0.52	
049	All 4	<35	60 - 53	4	4.09	Very cold
058	All 4	~90	91 - 78	140	0.21	1,037 mi indicated
068	All 4	175 - 69	98 - 82	180	0.20	
071	All 4	80 - 70	78 - 62	60	0.62	
071a	LFD, RFD	80 - 70	62 - 61	240	—	Negligible leak
089	All 4	~70	91 - 84	30	0.54	
091	LFD, RFD	~70	83 - 83	30	-0-	
121	All 4	~72	70 - 68	60	0.07	
128	All 4	~90	90 - 88	74	0.06	3,796 mi indicated
131	All 4	51	80 - 63	70	0.56	SDTDC post-calibr.
132	LFD, RFD	54	60 - 68	70	0.20	
142	LFD	55	97 - 40	15	1.14	Cold
143	RFD	55	93 - 93	15	-0-	
144	LRD	55	94 - 90	15	0.08	
145	RRD	55	95 - 95	15	-0-	
196	All 4	>80	90 - 80	170	0.13	
202	All 4	~75	79 - 77	210	0.02	4,455 mi indicated
208	All 4	110-90	79 - 75	110	0.08	
242	All 4	80	91 - 83	30	0.62	System engaged
243	All 4	80	96 - 86	30	0.74	System disengaged
244	All 4	80	91 - 81	30	0.58	System disengaged
247	All 4	70	89 - 88	30	0.07	7,098 mi corrected

PRESSURIZED HUB TIME

Data No.	Pressure (psi)	Hub temp. (°F)	Dyn/Stat	Hub No.	Time (min)
012	90 - 60	(overnight)	STAT	LFD	980
022	90 - 85	48 - 125	DYN	All	29
024	85	n/a	STAT	All	12
026	84	90 - 152	D/S	All	45
027	83 - 72	100 - 75	STAT	All	80
028	85	65 - 215	D/S	All	60
032	90 - 65	?	STAT	All	118
034	88 - 70	36 - 125	D/S	All	35
035	70 - 30	60 - 75	DYN	All	23
037	30	75	STAT	All	16
044	93 - 67	200 - 65	D/S	All	254
050	60 - 95	90 - 150	DYN	All	35
057	93	200 - 110	DYN	All	120
058	91 - 88	110 - 100	STAT	All	36
059	88 - 78	100 - 75	STAT	All	103
069	100 - 82	175 - 85	D/S	All	307
071a	78 - 61	75	STAT	All	60
071b	61	75	STAT	L, RFD	233
084	100	50 - 125	DYN	LFD	100
086	92	100 - 120	DYN	LFD	160
087	92 - 88	110 - 200	DYN	All	228
090	91 - 83	75	STAT	All	29
091	83	75	STAT	All	29
103	94 - 88	85 - 175	D/S	All	170
114	72	75 - 175	DYN	All	187
120	65	105	STAT	All	38
121	69	100 - 125	DYN	All	38
123	69	110	STAT	All	30
124	67	110 - 170	D/S	All	60
128	93	75 - 105	DYN	All	10
129a	93	105	STAT	All	72
129b	90	100	STAT	L, RFD	146
132	80 - 63	55	STAT	L, RFD	104
140	90 - 45	55	STAT	All	41
147	90	85	DYN	All	15
148	92	85	STAT	LFD	18
183	95 - 52	90	D/S	All	293
184	53 - 95	110	D/S	All	190
197	90 - 80	75	STAT	All	168
203	78	75	STAT	All	197
211	55 - 95	55 - 175	D/S	All	293
244	95 - 80	80	STAT	All	110
247	89 - 88	70	STAT	All	30
253	53 - 82	95	STAT	All	30
254-256	53 - 96	~90	STAT	All	50
257	50	92	STAT	All	60

CALIBRATION DATA

The following are uncorrected calibration (Cal) readings from the system 4 conditioner. Correct readings for the rpm channel (2) are 3.157 volts (631.4 rpm) and for the pressure channel (3) "0.668" (66.8 psi). In all cases, the channels were adjusted to their correct values before resuming testing.

Data No.	*Rpm* *Zero*	*Rpm* *Cal*	*Pressure* *Zero*	*Pressure* *Cal*	*Date*
047	0	3.157	0.001	0.668	2/20/90
054	0	3.168	0	-0.07	2/21/90
065	0	3.156	0.002	0.668	2/24/90
072	0	3.130	0	0.668	2/27/90
078	0	3.157	0	0.670	2/28/90
089	0	3.157	0.02	0.664	3/07/90
095	0	3.150	0	0.668	3/08/90
109	0	3.157	0	0.660	3/19/90
125	0	3.157	-0.02	0.671	3/21/90
129	-0.03	3.130	0	0.668	3/23/90
180	0	3.157	0	0.635	5/25/90
197	0	3.157	0.02	0.675	6/08/90
206	0	3.157	0	0.669	6/11/90
215	0	3.157	0	0.668	6/14/90