FIELD STUDY: VERIFICATION OF ADVANCES IN BEAM PUMPING DIAGNOSTIC SOFTWARE

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INTRODUCTION

Today's cutting edge diagnostic software for beam pumping surveillance, analysis, and optimization includes improved methodology based on time-tested techniques as well as practical new functionality. Specifically, this paper will reference dynamometer card pattern matching to aid the well analyst, lease operator, or other interested parties in understanding well operating conditions. This is technology available from the 1980's, but refined in the pattern matching algorithms used and the presentation of results to the user. Available new functionality includes diagnostic reporting that produces a collection of outputs or warnings which are the result of a statistical analysis of surface and downhole card information, calibration or predicted dynamometer card information, and trended data for each beam well addressed by the diagnostic software. The required data is gathered and the resulting calculations are performed each day by the diagnostic software. The purpose is to apply logic that an experienced well analyst would use to determine whether each well needs any corrective action. The diagnostic logic can be customized, allowing users to specify statistical limits for creating warnings. Those diagnostic warnings deemed unnecessary can be de-activated by the user.

Major areas of interest for this paper include: 1) recognition of RPC load calibration problems, 2) gearbox torque and pumping unit counterbalance, 3) correct prime mover size, and 4) verification of pattern matching usability. The field test will include beam pumped wells located in conventional primary recovery areas and wells pumping under the influence of injected CO_2 for secondary recovery. The data presented in this paper was randomly selected from wells in a 101 well system located in western United States. Average pumping depths ranged from 5400' to 6500'. All wells were equipped with RPCs (Rod Pumped Controllers), calibrated load cells (all with five years or less service), and some combination of magnetic proximity switches and inclinometers for position input. RPC and end device maintenance and software well configuration history should be consider as average.

DATA INTEGRITY

Any discussion of information gathered and used by beam pumping diagnostic software should include mention of the importance of correct well data configuration. Computer software follows the old adage, "Garbage in, garbage out!" The real power of the diagnostic software lies not in status and control, but in the analysis and presentation of data, reports, and trends. Diagnostic software requires that accurate data be entered up front and that, as an on-going process, data be kept up-to-date.

RPC LOAD CALIBRATION

What is meant by load calibration?

For the intent of this paper, load calibration will refer to the recognition of whether the load data being gathered by the diagnostic software is accurate enough to be used for: 1) complete well analysis, and/or, 2) system design calculations. Also, calibration can refer to the corrective actions needed when load data problems are found.

Why worry about calibration at all?

Correct load and position data is not a requirement for proper RPC operation, which depends only on the shape of the surface dynamometer card in order to detect pump off and on relative loads used to shut the well down when excessive high or low loads occur. However, diagnostic software programs rely on accurate input from the RPC data in order to give the user good analysis and design results. It is important to understand what benefits the diagnostic software can give the user when the RPC dynamometer data is correct or has been properly calibrated. Among those benefits are the following:

- Good downhole card shape for determination of pump condition, pump fillage, tubing anchor condition, gas compression, pump spacing, etc.
- More accurate top of stroke, RPC pump off and malfunction set-point determination.
- Correct pumping unit gearbox loading, including unit unbalance and counterbalance requirements to properly balance the unit.
- Accurate pumping unit walking beam (pumping unit structure) loading.
- Correct peak rod stress calculations.
- Correct pump displacement, which can be used to verify well testing results, as well as to track downhole pump efficiency.
- Calculated fluid levels. The user no longer has to depend solely on manual fluid level shots. Additionally, more accurate calculated fluid level trends would be available in the diagnostic software.
- Calculated PIP (Pump Intake Pressure) accuracy.
- Calculated electrical cost accuracy.

Load calibration results are made available to the user each day in a **Diagnostic Report**. See Figure 1.

Under the Details link, the user can see probable causes of the Load Calibration differences, as well as suggested solutions.

The load data presented in Table 1 was gathered from 50 wells surveyed out of a possible 101 wells in the host database. The diagnostic software compared actual load data from each RPC to data available from design calculations for each well. The deadband or allowable difference applied by the diagnostic software (user configurable) for each of the three listed load parameters (maximum, minimum, and load span) was 10%. An entry of OK means the parameter was calculated to be within the deadband.

<u>Results from 50 wells surveyed</u>:

- Measured maximum load vs. calculated maximum load:
    - 26 wells were within the 10% deadband.
    - 24 wells showed an average 22.4% difference.
- Measured minimum load vs. calculated minimum load
    - 14 wells were within the 10% deadband.
    - 36 wells showed an average 42.0% difference.
- Measured load span vs. calculated load span
    - 12 wells were within the 10% deadband.
    - 38 wells showed an average 29.8% difference.

Load calibration correction results on selected wells are shown in Table 2.

GEARBOX TORQUE AND PUMPING UNIT COUNTERBALANCE

It is always important for an operator to know the degree to which each pumping unit gearbox in his field is loaded (gearbox torque). Gearbox overloads can result in significant loss of useable gearbox life and will also affect the amount of energy needed to operate a rod pumped well. Correct diagnostic software calculation of gearbox torque is dependent on accurate load values from the RPC, selection of the proper API pumping unit, direction of unit rotation, and correct pumping unit counterbalance data. The most common cause of pumping unit gearbox overload is improper counterbalance.

Gearbox Torque and Balance results are made available to the user each day in a **Diagnostic Report**. See Figure 2.

Table 3 dramatically illustrates the role of counterbalance in the determination of gearbox torque. Note that the percent value calculated for the loss of useable gearbox life when a gearbox is overloaded is estimated based on industry recognized rule of thumb equations. The pumping unit gearbox load data presented in the Table 3 was gathered from 48 wells surveyed out of a possible 101 wells in the host database.

Results from 48 wells surveyed:

- 20 wells showed overloaded gearboxes:
  - Average gearbox torque overload was 39.7%.
  - Estimated loss of useable gearbox life was 58.8%.
  - Average unit unbalance was 29.7%.
  - Average torque if properly counterbalanced was 87.0%.
  - Average torque reduction per well if properly counterbalanced was 52.7%.
- 28 wells had gearbox torque less than rated value:
  - Average gearbox torque was 63.8%.
  - Average unit unbalance was 37.9%.
  - Average torque if properly counterbalanced was 43.2%.
  - Average torque reduction per well if properly counterbalanced was 20.6%.

The observed changes in torque calculations following load calibration correction are seen in Table 4.

PRIME MOVER SIZE

Electrical usage costs have become one of the leading operational costs of today's oil field. During the early days of beam pumping, production optimization and equipment loading were not points of prime consideration. Electrical costs were low and not generally considered important. Opportunities to reduce power consumption have therefore, to some extent, gone unnoticed. Because of rising fuel costs for electrical energy generation and the apparent effects of energy deregulation, operators will find it more and more important to find ways to operate beam pumped wells as efficiently as possible. The electrical prime movers used for powering beam pumping units are often overlooked as a source of decreasing electrical usage.

Oversized prime movers are inefficient and therefore use more energy than they should. The diagnostic software can accurately calculate, based on the amount of work represented by the surface dynamometer card, the prime mover size required for each well. After comparing this value with the actual size of the installed prime mover, the software will warn the user if a well can be operated with a smaller electric motor. A good rule of thumb is that required prime mover horsepower can be based on calculated PRHP X 2 for conventional pumping units or calculated PRHP X 1.75 for improved geometry units. Table 5 shows the well identified by the diagnostic software from the 101 well system with oversized prime movers.

PATTERN MATCHING

Today's diagnostic software includes functionality to help the everyday user understand observed well conditions as seen through dynamometer cards, both surface cards and/or the calculated downhole pump card. This capability is known as pattern matching.

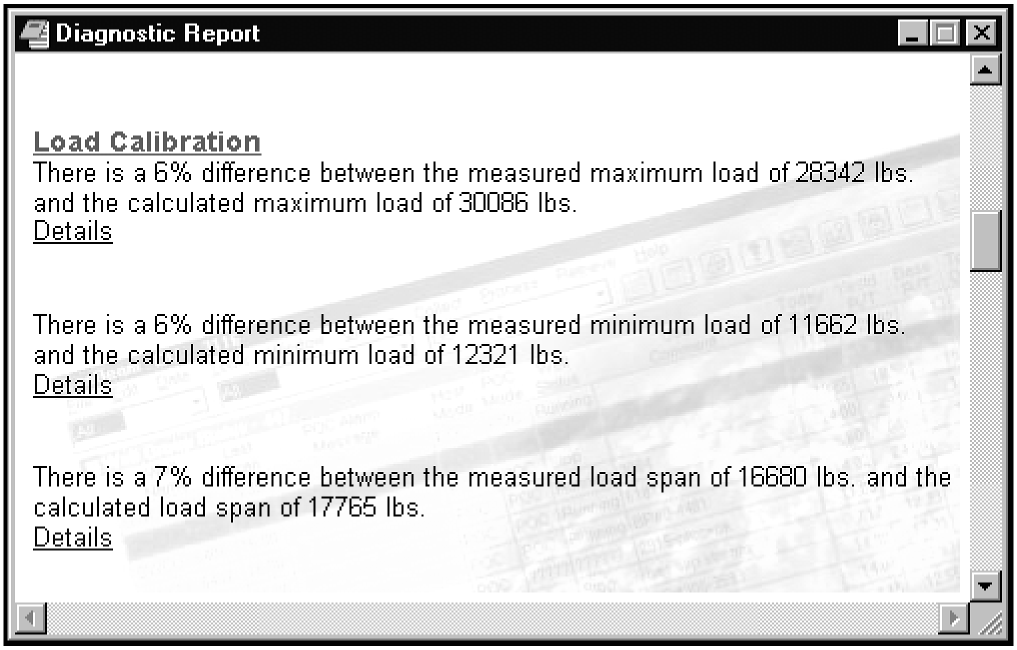
Cards are gathered from each well in the system every day at a time chosen by the user. If a well does not cycle, the system gathers a Current Card, or a Full Card if the well pumps off. The cards are then compared to all cards stored in the pattern matching library and the results displayed in a **Diagnostic Report** available to the user each morning. The user can choose to match only the surface card, the downhole card, or a combination of both cards based on a configurable minimum percent match. Only those cards that meet or exceed the selected percent match will be reported to the user. See Figure 3. The diagnostic software normalizes the cards stored in the pattern library. This means that all cards in the library are available for pattern matching, regardless of stroke length or load span.

The software is installed with a pattern card library in place. This library is completely open to the user. Cards can be added, deleted or existing card descriptions can be changed by the user. Further, any card in the pattern library can be overlaid with cards gathered from a well to confirm the validity of the pattern matching algorithm. See Figure 4.

Pattern matching is also available on demand if the user wishes to use the functionality anytime a card is gathered from a well.

Pattern matching is intended only as one of several factors available from the diagnostic software that the user can use to analyze the operating conditions of beam pumped wells. Important decisions such as pulling a well based solely on the results of this function on any well should be avoided. Remember that the accuracy of RPC load and position data varies from well to well. This is especially true of wells equipped with strain gauges and/or proximity switches. Two points of emphasis: 1) Well data configuration and load/position device calibration and maintenance is crucial, and 2) Users can improve the accuracy of pattern matching through verification of conditions representative of local pumping conditions as indicated by cards gathered by the system and then adding them to the pattern library.

For the purposes of this paper, pattern matching functionality can only be evaluated over a longer period of time. **Results will be available in the spring of 2001.**



Load Calibration

There is a 6% difference between the measured maximum load of 28342 lbs. and the calculated maximum load of 30086 lbs.
Details

There is a 6% difference between the measured minimum load of 11662 lbs. and the calculated minimum load of 12321 lbs.
Details

There is a 7% difference between the measured load span of 16680 lbs. and the calculated load span of 17765 lbs.
Details

Figure 1

Table 1

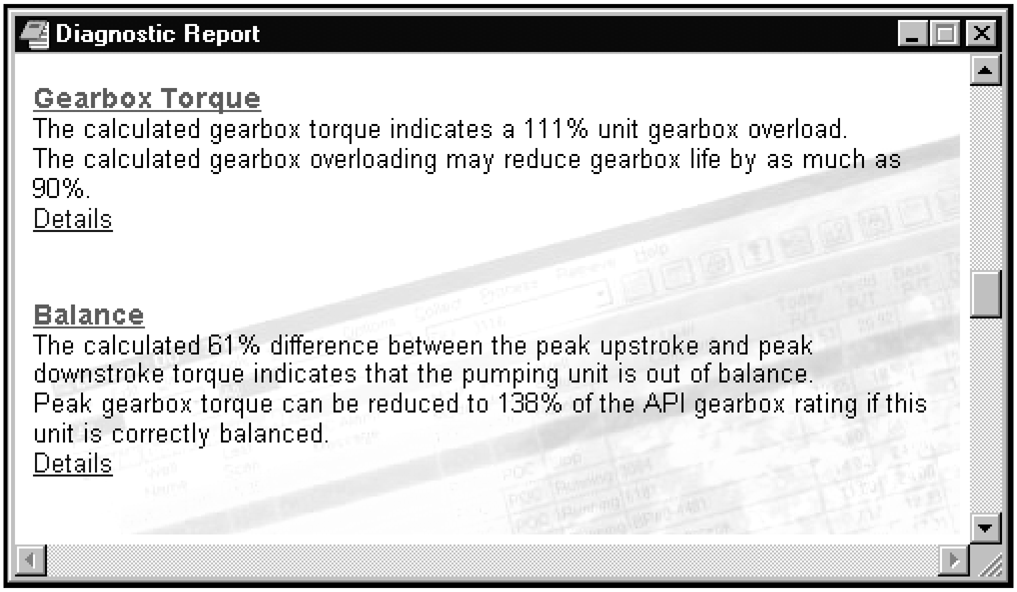
	Meas. Max. (Lbs)	Cal. Max. (Lbs)	% Diff	Meas. Min. (Lbs)	Cal. Min. (Lbs)	% Diff	Meas. Span (Lbs)	Cal. Span (Lbs)	% Diff
Well 1	14657	16350	12	8659	10126	17	OK	OK	OK
Well 2	14790	17391	15	6182	10508	42	8608	6883	26

Table 1

	Meas. Max. (Lbs)	Cal. Max. (Lbs)	% Diff	Meas. Min. (Lbs)	Cal. Min. (Lbs)	% Diff	Meas. Span (Lbs)	Cal. Span (Lbs)	% Diff
Well 3	23291	16724	44	17980	8663	108	5951	8061	27
Well 4	12450	19872	59	4654	8799	89	7796	11073	42
Well 5	OK	OK	OK	7242	6908	25	14048	11140	27
Well 6	OK	OK	OK	4533	10404	57	10858	5118	113
Well 7	14880	17217	14	9140	11790	23	OK	OK	OK
Well 8	8017	10613	25	OK	OK	OK	9422	7319	29
Well 9	16785	18967	12	OK	OK	OK	6974	8222	16
Well 10	13525	10079	35	OK	OK	OK	7892	9595	21
Well 11	17631	20923	16	13047	9038	45	4584	11885	62
Well 12	OK	OK	OK	3935	6121	36	18827	15837	19
Well 13	13582	16954	20	OK	OK	OK	3720	7037	48
Well 14	9225	11577	16	OK	OK	OK	OK	OK	OK
Well 15	19105	22605	16	7077	10490	33	OK	OK	OK
Well 16	22912	25531	11	6470	4671	39	16442	20860	22
Well 17	OK	OK	OK	3727	8651	57	16898	13416	26
Well 18	OK	OK	OK	6850	9731	30	14377	12420	16
Well 19	OK	OK	OK	3887	6141	37	18853	16074	18
Well 20	18792	22871	18	11832	9862	20	6960	13009	47
Well 21	18225	21836	17	8055	10278	22	10170	11558	13
Well 22	OK	OK	OK	7292	8378	13	15118	13375	14
Well 23	OK	OK	OK	5270	4268	24	17087	20380	17
Well 24	OK	OK	OK	OK	OK	OK	OK	OK	OK
Well 25	OK	OK	OK	7714	5062	53	15759	17723	12
Well 26	16674	20827	20	7746	9822	22	8928	11005	19
Well 27	25030	28382	12	OK	OK	OK	18630	22115	16
Well 28	OK	OK	OK	5967	7783	24	OK	OK	OK
Well 29	OK	OK	OK	OK	OK	OK	9843	11276	13
Well 30	OK	OK	OK	OK	OK	OK	OK	OK	OK
Well 31	17967	20821	14	OK	OK	OK	10095	12784	22
Well 32	OK	OK	OK	6100	8643	30	15682	12235	29

Table 1									
	Meas. Max. (Lbs)	**Cal. Max. (Lbs)**	**% Diff**	**Meas. Min. (Lbs)**	**Cal. Min. (Lbs)**	**% Diff**	**Meas. Span (Lbs)**	**Cal. Span (Lbs)**	**% Diff**
Well 33	20325	24958	19	5870	9807	41	OK	OK	OK
Well 34	15000	21987	32	OK	OK	OK	4373	12195	65
Well 35	OK	OK	OK	OK	OK	OK	OK	OK	OK
Well 36	14158	18386	23	OK	OK	OK	6067	9376	36
Well 37	OK	OK	OK	5627	11159	50	13680	10230	34
Well 38	OK	OK	OK	7350	10544	31	13900	9621	45
Well 39	OK	OK	OK	4195	8037	48	17367	14321	22
Well 40	OK	OK	OK	8162	9270	12	14185	11754	21
Well 41	OK	OK	OK	6868	2750	150	14600	17574	17
Well 42	OK	OK	OK	9542	11293	16	7805	6678	17
Well 43	16325	23616	31	1187	6155	81	15138	17461	14
Well 44	OK	OK	OK	6182	9708	37	11570	8176	42
Well 45	18695	21093	12	6170	8792	30	OK	OK	OK
Well 46	22090	19209	31	6445	9287	31	15645	9922	58
Well 47	16790	19383	14	6460	7491	14	10330	11892	14
Well 48	OK	OK	OK	OK	OK	OK	OK	OK	OK
Well 49	OK	OK	OK	8810	6858	29	11740	13822	16
Well 50	OK	OK	OK	3427	10225	67	17983	12809	41

Table 2									
	Meas. Max. (Lbs)	**Cal. Max. (Lbs)**	**% Diff**	**Meas. Min. (Lbs)**	**Cal. Min. (Lbs)**	**% Diff**	**Meas. Span (Lbs)**	**Cal. Span (Lbs)**	**% Diff**
Well 2	14790	17391	15	6182	10508	42	8608	6883	26
Calib. Values	17232	17391	1	10352	10508	2	6880	6883	0
Well 4	12450	19872	59	4654	8799	89	7796	11073	42
Calib. Values	19750	19872	6	8238	8799	6	11512	11073	4
Well 6	OK	OK	OK	4533	10404	57	10858	5118	113
Calib. Values	OK	OK	OK	10123	10404	3	5173	5118	1



Gearbox Torque

The calculated gearbox torque indicates a 111% unit gearbox overload.
The calculated gearbox overloading may reduce gearbox life by as much as 90%.
Details

Balance

The calculated 61% difference between the peak upstroke and peak downstroke torque indicates that the pumping unit is out of balance.
Peak gearbox torque can be reduced to 138% of the API gearbox rating if this unit is correctly balanced.
Details

Figure 2

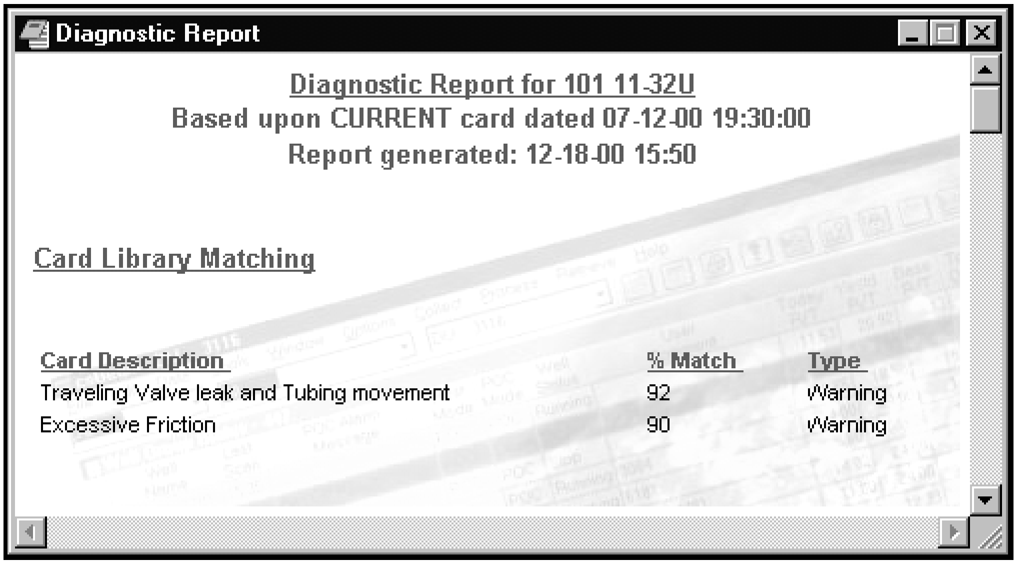
Table 3

	GB Torque %	Est. GB Life Loss %	Balance Up/Down Diff. %	In-balance Torque %
Well 1	146	68	46	112
Well 2	87	--	67	47
Well 3	40	--	22	27
Well 4	40	--	13	39
Well 5	56	--	31	41
Well 6	93	--	18	85
Well 7	161	77	24	90
Well 8	90	--	7	86
Well 9	67	--	32	55
Well 10	64	--	46	21
Well 11	109	23	19	61
Well 12	128	53	57	91
Well 13	79	--	6	60
Well 14	173	81	15	42
Well 15	12	--	20	11
Well 16	134	58	66	89
Well 17	22	--	58	16
Well 18	92	--	41	76

Table 3				
	GB Torque %	**Est. GB Life Loss %**	**Balance Up/Down Diff. %**	**In-balance Torque %**
Well 19	34	--	23	30
Well 20	173	96	10	28
Well 21	138	62	28	122
Well 22	142	65	7	102
Well 23	30	--	65	18
Well 24	63	--	61	37
Well 25	35	--	44	27
Well 26	44	--	41	37
Well 27	161	76	31	61
Well 28	106	15	5	102
Well 29	105	13	50	75
Well 30	95	--	9	91
Well 31	142	93	20	65
Well 32	50	--	59	32
Well 33	169	80	24	32
Well 34	47	--	10	40
Well 35	89	--	56	21
Well 36	127	51	22	113
Well 37	183	84	28	73
Well 38	131	52	3	51
Well 39	40	--	72	23
Well 40	89	--	91	83
Well 41	53	--	48	41
Well 42	133	57	40	62
Well 43	26	--	24	33
Well 44	118	38	46	70
Well 45	24	--	2	24
Well 46	72	--	62	46
Well 47	114	33	14	98
Well 48	76	--	32	62

Table 4				
	GB Torque %	Est. GB Life Loss	Balance Up/Down Diff.	In-balance Torque
Well 2	87	--	67	47
	40	--	57	28
Well 6	93	--	18	85
	136	61	47	98
Well 8	90	--	7	86
	116	36	1	115

Table 5			
	Cal. PRHP	Installed Prime Mover HP	Calculated Req. HP
Well 1	7.0	25	15
Well 2	5.4	30	15
Well 3	8.3	50	20
Well 4	12.1	50	25
Well 5	10.1	40	25
Well 6	5.9	40	15
Well 7	9.5	40	20
Well 8	4.5	40	10
Well 9	7.3	40	15
Well 10	18.6	50	40
Well 11	8.3	50	20
Well 12	5.2	40	15
Well 13	20.2	60	50
Well 14	2.3	50	10
Well 15	12.6	40	30
Well 16	13.7	50	30

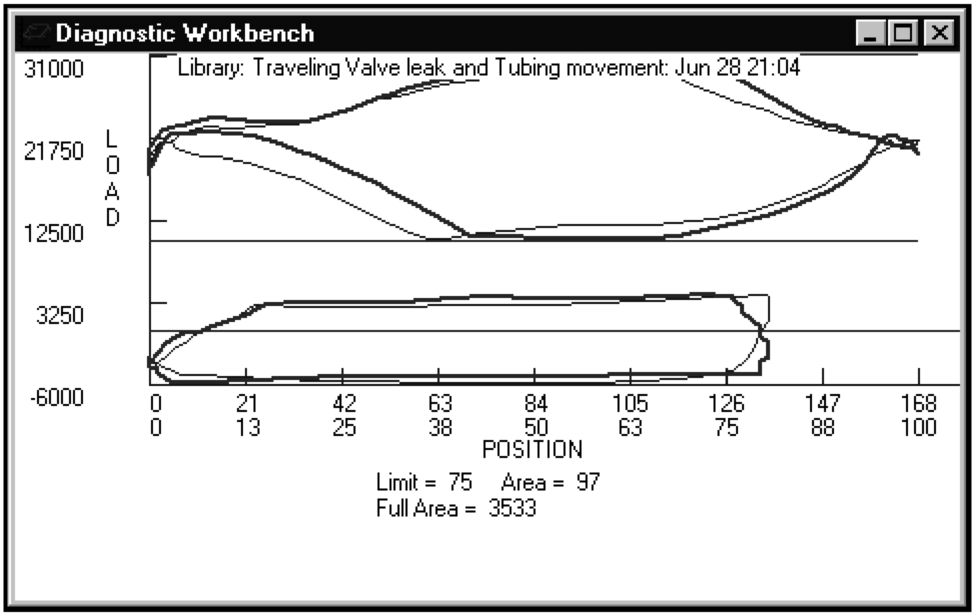


Diagnostic Report for 101 11-32U
Based upon CURRENT card dated 07-12-00 19:30:00
Report generated: 12-18-00 15:50

Card Library Matching

Card Description	% Match	Type
Traveling Valve leak and Tubing movement	92	Warning
Excessive Friction	90	Warning

Figure 3



Library: Traveling Valve leak and Tubing movement: Jun 28 21:04

Limit = 75 Area = 97
Full Area = 3533

Figure 4