PATTERN RECOGNITION APPLIED TO DYNAMOMETER CARDS FOR SUCKER ROD PUMPING DIAGNOSIS

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ABSTRACT

This paper discusses a numerical pattern recognition scheme NUPRO[1]. NUPRO is used to diagnose rod or subsurface pump problems by recognizing downhole dynamometer cards. NUPRO discretizes a dynamometer card into a set of points. Three point picking methods have been developed for NUPRO: constant position increment, constant time increment, and constant arc length increment. These methods vary the accuracy and run time of NUPRO. These methods were tested with a library of 37 known cards (cards 1-37) and 100 unknown cards (cards 38-137).

INTRODUCTION

The sucker rod pumping system is the most widely used form of artificial lift for oil wells. Because of the wide applicability of sucker rod pumping systems, proper maintenance can have a significant effect on income and reserves. Thus, a technique that will allow quick and accurate diagnosis of conditions at the subsurface pump and the sucker rod string must be used. A modern technique that can be used is pattern recognition using downhole dynamometer cards. The need for this modern technique is the primary motivation for developing NUPRO, a tool that allows quick detection and diagnosis of problems by monitoring a well. NUPRO is a numerical pattern recognition scheme. For problem detection, NUPRO uses a detective library of "healthy " surface dynamometer cards. For problem diagnosis, NUPRO uses a diagnostic library of characteristic downhole dynamometer cards. Each characteristic downhole dynamometer card is coupled with a specific problem. NUPRO's diagnostic library can be continuously improved by adding new characteristic problem cards. NUPRO has three main applications in the oil field: -Problem detection, -Problem diagnosis, -Pump off controller. This paper will focus on problem diagnosis and the influence of different point picking strategies on NUPRO's accuracy.

BACKGROUND

Expert systems are used to diagnose subsurface pump problems. These expert systems work with a database of "healthy" and "nonhealthy" downhole dynamometer cards or templates. This database of cards or templates is the library used for pattern

recognition. To diagnose a subsurface pump problem, the downhole dynamometer card from a well is matched with the most similar card or template from the library using a pattern recognition algorithm. If the matched library card or template is healthy, the expert system's response is do nothing. If the best matched library card or template is unhealthy, then the problem associated with that particular library card or template is attributed to that well.

If the well's card does not match the library card or template - ie poor correlation coefficient for the match, then that irregular card or template should be added to the library once its problem has been identified. This process will maintain and upgrade the library for improved problem diagnosis in the future.

In conclusion, a significant change in the shape of a "healthy" downhole dynamometer card to that of an "unhealthy" card or a condition with a low correlation coefficient will indicate a problem with the pump or rod string.

Previous work similar to NUPRO is in EXPROD[2]. The pattern recognition scheme used by EXPROD is illustrated by Figures 1 and 2. The EXPROD pattern recognition scheme uses templates to recognize downhole dynamometer cards. The template used to recognize fluid pound is illustrated by Figure 3. The degree of matching is proportional to the number of successful intersects between the horizontal bars of the template and the dynamometer card. However, as shown in Figure 4, this methodology does not consider the entire dynamometer card shape.

To consider the shape of all of the dynamometer card, NUPRO takes the following steps:

- Scale the cards between one and two.
- Pick N points from the cards. Each point consists of two numbers (polished rod position, polished rod load). The following point picking methods can be used: constant time increment, constant position increment, constant arc length increment. Consequently, the **point picking strategy** is very important for the accuracy and run time of "NUPRO".
- Represent the chosen N points as one 2N dimensional vector.
- Normalize the 2N dimensional vector.

After performing the previous steps, NUPRO is able to recognize the library card that is the most similar to the unknown card. This recognition is accomplished by calculating the dot product between a scaled and normalized 2N dimensional library vector and a scaled and normalized 2N dimensional unknown vector. The largest dot product gives the best match in the library. Therefore, it is very important to have a complete range of healthy and problem cards in library. If the highest correlation coefficient is low, then the program decides that the recognition is incorrect.

NUPRO's procedure

The steps used to numerically recognize dynamometer cards are :

1. Obtain a library database of known dynamometer cards.
2. Change the known dynamometer cards into known scaled and normalized 2N dimensional vectors. Note: Steps to change a dynamometer card into a scaled and normalized 2N dimensional vector are listed below.
3. Store the known normalized vectors in a library.
4. Obtain an unknown dynamometer card from the well being monitored.
5. Change the unknown dynamometer card into an unknown scaled and normalized 2N dimensional vector.
6. Dot the unknown scaled and normalized vector with all of the known scaled and normalized library vectors.
7. Find the library vector with the highest dot product (correlation coefficient).

The steps used to change a dynamometer card into a scaled and normalized 2N dimensional vector are :

1. Scale the force and the position of the dynamometer card between one and two.
2. Pick N points consistently from the scaled dynamometer card. Note: Reference the point picking section of this report.
3. Obtain a force and a position for each point (2N numbers).
4. Create a 2N dimensional vector for each card. Do this by arranging the 2N numbers in some sequence. The same sequence must be used for all the cards. One way is to have N position numbers followed by N force numbers. Another way is to alternate position and force numbers.
5. Obtain the length of the vector. (The length of the vector is the square root of the sum the of squares.)
6. Normalize the length of the vector. (Divide each number in vector by the length of the vector.)

PROBLEM STATEMENT

A very important step in NUPRO is the point picking step. Three strategies are tested to optimize this step. All the point picking strategies distort the dynamometer card in some way. Therefore, the point picking strategy affects NUPRO's accuracy.

The objective of this paper is to show some advantages and disadvantages of the different point picking strategies.

POINT PICKING STRATEGIES -METHODOLOGY-

Several point picking strategies can be used with an expert system that uses NUPRO. The three point picking strategies that are discussed in this section are:

- Constant time increment
- Constant position increment
- Constant arc length increment

All the point picking strategies distort the dynamometer card in some way. Scaling the position between one and two, and normalizing the length of the vectors also distort dynamometer cards. Since scaling and normalizing are necessary with this dot product pattern recognition algorithm, this section will only focus on point picking distortions.

The dynamometer card distortions take place in the following order:

- Scaling distortion
- Point picking distortion
- Normalizing vector distortion.

There is one advantage in the scaling distortion which distorts any rectangle into a square. The advantage is that we only need one anchored healthy dynamometer card in the database to represent all the possible anchored healthy dynamometer cards regardless of pump stroke length. This is true because all anchored healthy downhole dynamometer cards are rectangles.

There are disadvantages in the scaling distortion. One disadvantage is that a stuck traveling valve card can be a thin rectangle. (See problem cards in appendix.) If it is scaled into a square, it will appear to be an anchored healthy dynamometer card. So, changing every rectangle into a square could change a problem downhole dynamometer card into a seemingly healthy downhole dynamometer card. A description of the different point picking strategies follows.

Constant position increment:

For this point picking strategy, we built a constant increment scale on the position axis. Then, we pick points using this constant position increment scale. This is illustrated by Figure 5.

Constant time increment:

To chose constant time increment points, the motion of the pump must be assumed or calculated. The motion is assumed since the information needed to calculate the motion is not given. Assuming simple harmonic motion the following formula can be used to build a constant time increment scale on the position axis. Finally, points are picked using the constant time increment scale. This is illustrated by Figure 6.

$P(I+1) = 0.5 * (COS((I+NOPL/2) * 2pi/NOPL) +1) +1$
P = position
I = the number of the point
NOPL = the number of points we are picking.

Constant arc length:

This method did not perform for two reasons. First, the initial point at which to begin the arc length could not be defined in a consistent manner. Second, the point picking scale depends on the arc length of the card and each card has a unique arc length.

COMPARISON & RESULTS

A database of 137 artificial downhole dynamometer cards is used to test the three point picking strategies. The first 37 cards are library cards (cards 1-37). The rest of the cards are unknown cards (cards 38-137). Each card has 50 data points. This number of data points seems to be the lowest number of data points that can properly define a dynamometer card for this pattern recognition algorithm. Some of these 137 cards are very similar in order to challenge the point picking strategy and the pattern recognition algorithm. The artificial cards are not originally scaled between one and two, or normalized.

The following study is based on the analysis of the different point picking strategies: constant position, constant time, constant arc length. Some of the matches obtained from the different point picking strategies are unsatisfactory. These unsatisfactory results are in arrays illustrated in Tables 1 and 2. Visual comparison of the dynamometer cards was used to define what a correct match is. Comments on the match obtained are also include in these arrays.

Wrong pattern recognition :

There are three main problem groups which often cause a wrong match between similar cards in the library.

The first problem group is:
- Card no. 2: Full Pump Anchored Tubing
- Card no. 4: Full Pump, Unanchored Tubing or Tubing Anchor not Holding

They both look like rectangles

The second problem group is:
- Card no. 6 : Severe Fluid Pound - Unanchored Tubing
- Card no. 7 : Severe Fluid Pound - Anchored Tubing
- Card no. 8 : Completely Pumped Off - Anchored Tubing

- Card no. 10: Completely Pumped Off - Unanchored tubing
- Card no. 14: Gas Interference

They all look similar (see appendix)

The third problem group is:

- Card no. 3 : Full Pump - Fluid friction
- Card no. 26: Slightly Worn Up - Leaking Valves
- Card no. 27: Worn Pump - Leaking SV & TV or Plunger
- Card no. 28: Worn Out Pump - Parted Rods or Flowing Well
- Card no. 29: Worn Pump - Leaking Valves

They look like circles

CONCLUSION

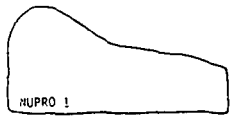
NUPRO is an accurate and fast way to diagnose sucker rod problems using either surface or downhole dynamometer cards. NUPRO gives results that are easy to interpret. The point picking strategy gives NUPRO the ability to distinguish between nearly identical downhole dynamometer cards. Between the three point picking strategies developed, the constant position strategy is considered as the best one. The lowest number of points that can be used to properly define a dynamometer card for pattern recognition seems to be 50 points.

REFERENCES

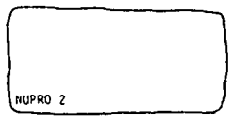
1. J. F. Keating, R. E. Laine, and J.W. Jennings: "Pattern Recognition Applied to Dynamometer Cards", SPE 19394

2. W. L. Foley and J. G. Suinos, Chevron Oil Field Research Co: "EXPROD: Expert Advisor Program for Rod Pumping" , SPE 16920

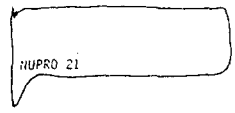
APPENDIX A



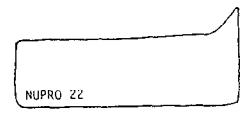
FULL PUMP - FLUID ACCELERATION (FRICTION)



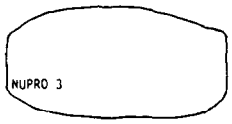
FULL PUMP ANCHORED TUBING



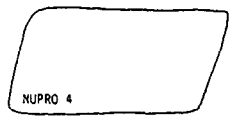
PUMP HITTING DOWN (SPACED TOO LOW)



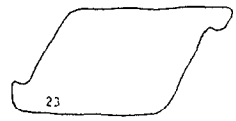
PUMP HITTING UP (SPACED TOO HIGH)
inverted pump hitting down



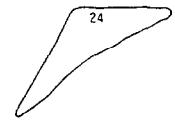
FULL PUMP - FLUID FRICTION



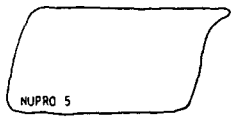
FULL PUMP, UNANCHORED TUBING
OR TUBING ANCHOR NOT HOLDING



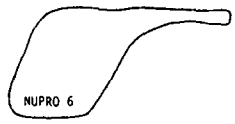
MALFUNCTIONING TUBING ANCHOR



SANDED UP PUMP - STUCK PLUNGER

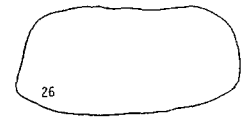


SLIGHT FLUID POUND - UNANCHORED TUBING

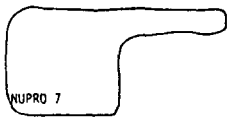


SEVERE FLUID POUND - UNANCHORED TUBING

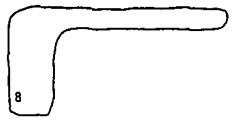
MALFUNCTIONING TUBING ANCHOR



SLIGHTLY WORN PUMP - LEAKING VALVES

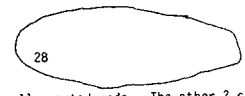


SEVERE FLUID POUND - ANCHORED TUBING



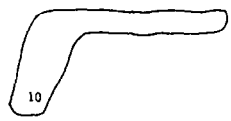
COMPLETELY PUMPED OFF - ANCHORED TUBING

Actually a worn pump. The other
WORN PUMP, LEAKING SV & TV OR PLUNGER
3 cases look the same.



Actually parted rods. The other 2 cases
WORN OUT PUMP, PARTED RODS OR FLOWING WELL
look the same.

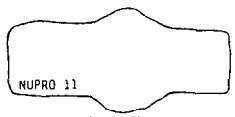
PARTED TUBING



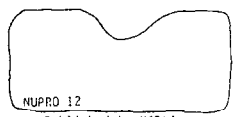
COMPLETELY PUMPED OFF - UNANCHORED TUBING

WORN PUMP - LEAKING VALVES

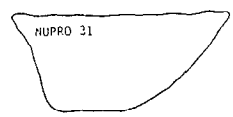
WORN PUMP



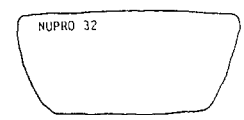
Published by NABLA
BENT OR STICKING BARREL
(an extreme case)



Published by NABLA
WORN OR SPLIT BARREL
(an extreme case)



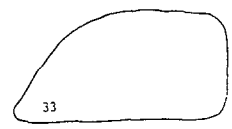
COMBINED LEAKING STANDING
VALVE AND GAS INTERFERENCE



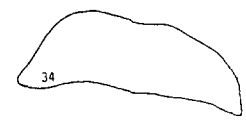
LEAKING STANDING VALVE

SEVERE GAS INTERFERENCE

GAS INTERFERENCE

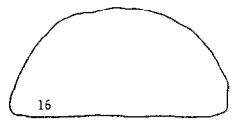


COMBINED UNANCHORED TUBING
AND LEAKING TRAVELING VALVE



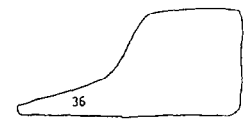
TRAVELING AND STANDING VALVE
BALLS SPLIT IN HALF

GAS LOCKED PUMP

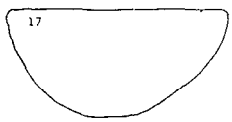


SEVERE TRAVELING VALVE OR PLUNGER LEAK

PUMP PLUNGER STICKING
ON THE UPSTROKE



INCOMPLETE PUMP FILLAGE
FOR UPPER RING VALVE PUMP
Published by NABLA.



SEVERE STANDING VALVE LEAK

LEAKING TRAVELING VALVE OR PLUNGER

BENT OR STICKING BARREL
Published by NABLA.
An extreme case.

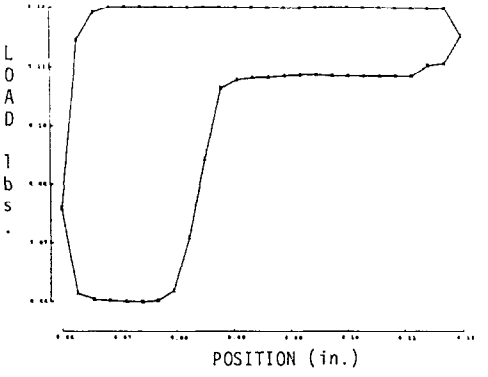
SEVERE STANDING VALVE LEAK

COMBINATION OF LEAKING STANDING AND
TRAVELING VALVES AND GAS INTERFERENCE

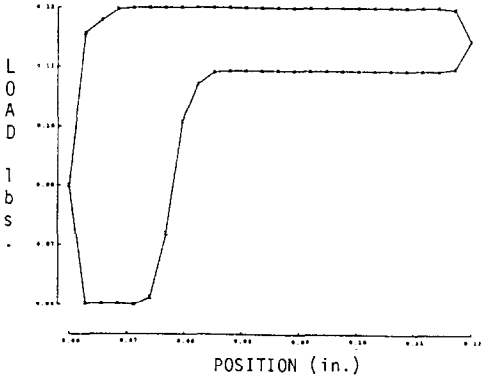
APPENDIX B

UNKNOWN CONSTANT POSITION CARDS

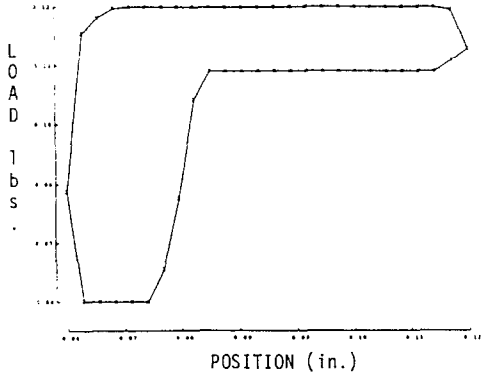
CARD No. 57



CARD No. 59

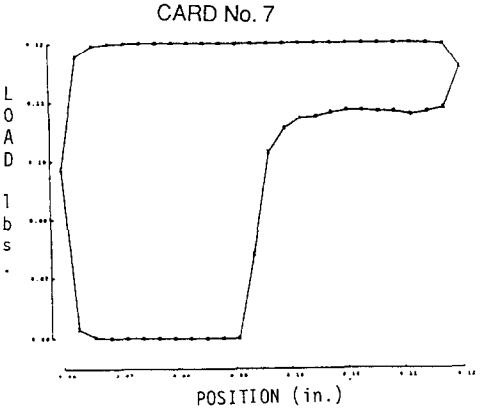


CARD No. 62

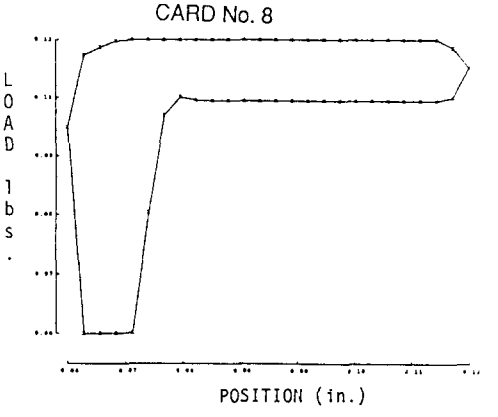


LIBRARY CONSTANT POSITION CARDS

CARD No. 7



CARD No. 8



CARD No. 10

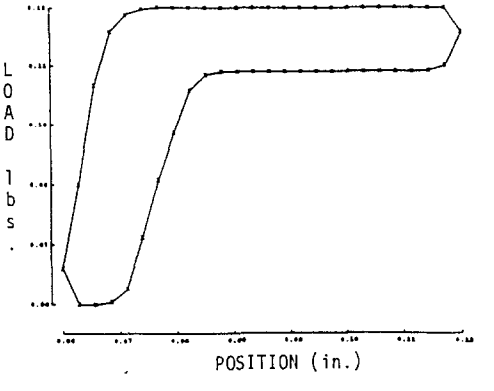


Table 1
Constant Time Increment Comparison Array

WELL CARD NUMBER	MATCH	MATCH EXPECTED	COMMENTS
57	7	10	similar but 7 little better / 10
59	8	10	similar but 8 little better / 10
62	8	10	similar but 8 little better / 10
77	18	12	12 is the best match
82	13	24	24 is the best match
120	28	3	3 is the best match

Table 2
Constant Position Increment Correction Array

WELL CARD NUMBER	MATCH FROM POSITION	MATCH FROM TIME	COMMENTS
57	10	7	similar but 7 better
59	10	8	similar but 8 better
62	10	8	similar but 8 better

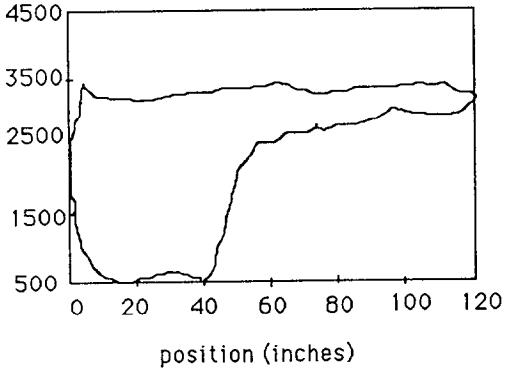


Figure 1 - Actual pump dynamometer card showing severe fluid pound

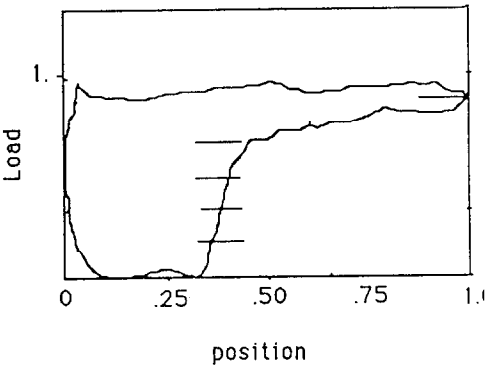


Figure 2 - Comparison of dimensionless pump dynamometer card with fluid pump template

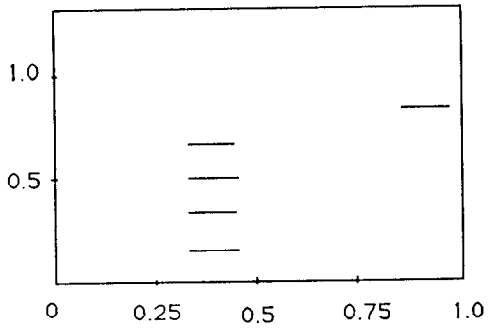


Figure 3 - Example template used to identify fluid pound

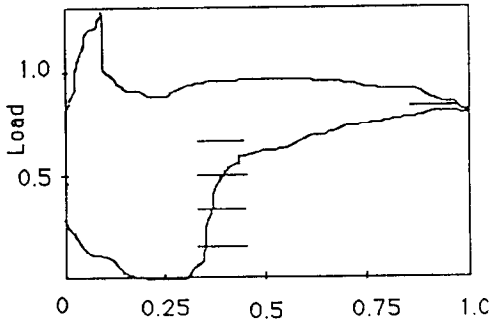


Figure 4 - Template accuracy failed

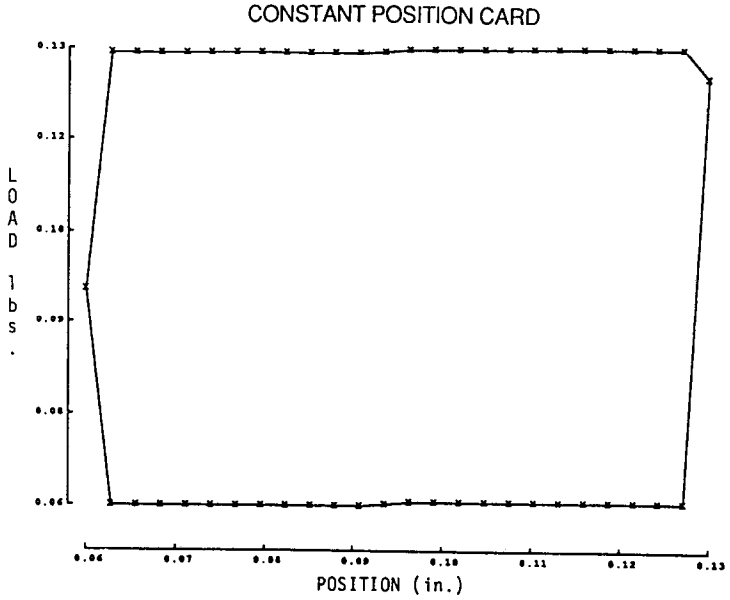


Figure 5

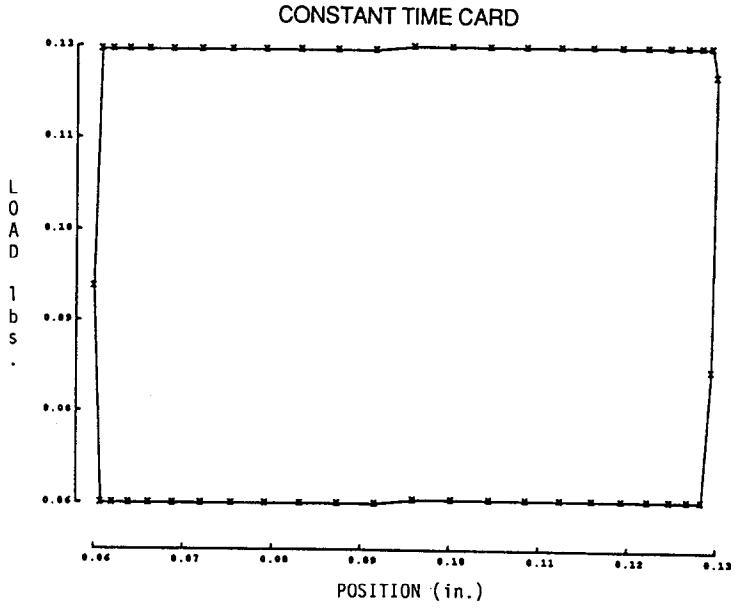


Figure 6