EFFECT OF INPUT DATA ERRORS ON DIAGNOSTIC ANALYSIS OF ROD PUMPS

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ABSTRACT

When interpreting the output of wave equation based computer programs, one must be able to accurately detect problems and recommend solutions. Several papers have been published describing techniques for calculation of gearbox loading, rod stresses, and downhole pump dynamometer cards. Included in these papers are downhole dynamometer card shapes corresponding to common pump problems that can be compared with calculated pump dynamometer cards to determine what is wrong with the pump. However, these techniques assume that the input data is correct.

This paper addresses interpretation errors that occur due to wrong input data. It discusses the effect of input data errors on key calculated parameters and how the analyst can detect them.

INTRODUCTION

Modern dynamometer diagnostic techniques that use the wave equation to calculate downhole dynamometer cards from measured surface dynamometer data are now used by several oil and service companies. The benefits of applying these techniques have been well documented [1],[2],[3]. The ability to quickly calculate gearbox and pumping unit structure loading, rod string stresses, and most importantly, downhole pump dynamometer cards allows more time for optimizing well performance. The advantages of using downhole dynamometer card shapes to diagnose pump problems are clear to anyone who has tried to troubleshoot rod pumped wells using surface dynamometer cards alone.

A surface dynamometer card is a plot of polished rod load versus position. Dynamometer cards are recorded with a dynamometer system that includes load and position transducers and an X-Y plotter or a portable computer that stores dynamometer data. The shape of the surface dynamometer card depends on several factors including well depth, strokes per minute, plunger size, pump operating condition, rod string design and material, pumping unit, prime mover type, etc. The downhole dynamometer card is a plot of load versus position at the pull rod of the pump. It is calculated by solving the wave equation [4] which is a mathematical model of the rod string. The downhole dynamometer card shape depends only on the operating condition of the pump. Therefore, it is much easier to detect pump problems such as leaking valves, worn plunger, gas interference, fluid pound, pump hitting down, and many others. Computer programs such as Chevron's SADA (Surface And Downhole Analysis) [3],[5] use the wave equation to "translate" the

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recorded polished rod dynamometer card into a corresponding downhole dynamometer card. The well analyst compares the calculated downhole dynamometer card with known card shapes to determine the operating condition of the pump.

Papers by Patton [1] and Gibbs [4] show several typical downhole dynamometer card shapes for full pump, fluid pound, leaking standing valve, leaking traveling valve or plunger, malfunctioning tubing anchor, and gas interference. Figure 1 shows some additional downhole pump dynamometer card shapes for common pump problems.

Dynamometer Card Interpretation Problems

Although catalogs of known dynamometer card shapes simplify card interpretation, the field dynamometer analyst is many times faced with downhole dynamometer card shapes that are different from the ones he is familiar with. From the experience of assisting dynamometer analysts in several fields locations, I found two main reasons for this problem. They are:

1. Pump dynamometer card shapes representing a combination of two or more problems.

2. Incorrect input data.

The first problem is due to more than one downhole pump problem occurring at the same time, such as malfunctioning tubing anchor and leaking traveling valve, gas interference and leaking standing valve, or other combinations. Although it is relatively simple to diagnose single problems such as fluid pound or leaking traveling valve, diagnosis becomes increasingly difficult as two or more problems occur simultaneously. Downhole dynamometer card shapes corresponding to verified pump problems are useful but do not solve this interpretation problem since many different combinations are possible. Figure 1 shows some examples of dynamometer card shapes corresponding to combinations of problems. A solution to this problem is educating the field analyst so that he or she understands how downhole pumps work and the relationship between pump problems and dynamometer card shape.

The second problem occurs when the analyst enters incorrect data in the computer program. The following data is typically required to obtain a pump card using a wave equation program:

1. A polished rod dynamometer card;
2. Diameter and length of each rod section;
3. Pumping speed;
4. Stroke length.

Errors in pumping speed, load scale, crank hole number, sucker rod diameter or length, etc. have an impact on diagnostic calculations.

The effects of these errors range from no effect for minor errors, to unnecessary pulling jobs, frustration, and loss of credibility for the analyst and the technology. This paper deals with ways to detect input data errors by looking for clues in calculated downhole dynamometer card shapes and other parameters. Diagnostic analyses from two actual wells (Case 1 and Case 2) will be used as examples. They are representative of the examined cases in this study. Figures 2 to 5 show the correct four page SADA computer program printout for Case 1. This well will be used to show the effect of the majority of input data errors discussed here. Case 2 will be used to show the effect of missing points when digitizing surface dynamometer cards.

PUMPING SPEED ERRORS

Pumping speed errors occur either because of incorrect field measurement or because no measurement was made at all. Trying to count how many strokes "fit" in one minute is a common method of measuring pumping speed that can result in errors. Also, assuming the speed is the same as last time the well was analyzed is another way to enter wrong pumping speed. This is especially true with ultra high slip motors whose speed is greatly dependent on torque changes. A changing fluid level that throws the unit out of balance will also change the pumping speed.

To study the effect of pumping speed errors, Case 1 was analyzed by entering pumping speeds that were +20%, -20%, +40% and -40% of the correct value. Figure 6 shows the effect of these errors on the shape of the calculated downhole dynamometer card. As you can see, a higher than actual pumping speed causes the downhole card to rotate counterclockwise. Also, a shorter gross pump stroke is calculated. A lower than actual pumping speed has the opposite effect. The card is rotated clockwise and the gross pump stroke is longer than actual. The clockwise rotation slants the card sides and may lead to the incorrect conclusion that the tubing is unanchored. Also notice the overall shape distortion, especially for the +40% and -40% cases.

In addition to downhole dynamometer card distortions, a pumping speed error has a direct impact on the calculated production rate and polished rod horsepower since these numbers are directly proportional to pumping speed. The effect on other parameters that are indirectly affected by pumping speed are summarized in Table 1. The system efficiency is defined as the minimum energy required for the present fluid production rate divided by the energy consumed by the prime mover.

LOAD SCALE ERRORS

There are two potential sources of load scale errors: a load cell that is out of calibration and digitizing errors. Digitizing errors when using dynamometer cards from an X-Y plotter can be eliminated by using a computer dynamometer system that records polished rod load and position and then transfers the data to the computer electronically. However, load cells go out of calibration regardless of dynamometer system.

Fortunately, the calculated downhole dynamometer card can provide strong clues that the load scale may be in error. Figure 7, illustrates the effect of load scale errors on calculated downhole dynamometer card shape. The main clues to these errors are the slant on the card sides and the shift in the load scale of the calculated downhole dynamometer card.

For a less than actual load scale, the downhole card sides slant from left to right. This has the same appearance as unanchored tubing and can lead to the incorrect diagnosis that the tubing anchor is not holding. However, the slant of the card's sides is not the only effect of this error. The calculated pump card loads also shift down resulting in mostly negative loads that are unrealistic.

For a higher than actual load scale, the opposite trend is observed. As Figure 7 shows, the card sides tilt from right to left and the downhole pump card loads are unrealistically high. Table 2 summarizes the effect of load scale errors on parameters that are indirectly affected by load. This table shows that for system efficiency and peak torque the results are unpredictable. In other words there is no trend with either magnitude or direction of error. Peak gearbox torque is a function of both polished rod load and counterbalance effect. Therefore, depending on unit balancing, incorrect polished rod load may result in peak torque that is either higher or lower than actual. System efficiency is a function of prime mover horsepower which in turn is a function of cyclic load factor. The cyclic load factor is a function of calculated torques. Therefore, system efficiency results are also unpredictable.

ROD STRING LENGTH ERRORS

Although not as common as load scale errors, wrong lengths of sucker rod sections in a tapered design can be entered in the diagnostic analysis program. Possible reasons for the errors include well records that have not been updated since the last rod string design change, or simply an error by the analyst when calculating the length of each taper.

Figure 8 shows the effect of entering incorrect rod lengths on the calculated downhole dynamometer card for Case 1. Figure 8a shows the effect of entering a length of 1345 ft for the one inch section and 2625 ft for the 7/8 inch section (an error of 500 ft). In this case the total depth was correct. The dynamometer card was shifted up but the effect is relatively small. Figure 8b shows the effect of entering a length of 4750 ft for the 3/4 inch section, which is 1000 ft longer than actual. The error caused the calculated downhole dynamometer card to shift down and have a right to left slant of its sides. Figure 8c shows the effect of entering a length of 2750 ft for the 3/4 inch section which is 1000 ft shorter than actual. The error caused the calculated downhole card to shift up and to have a left to right slant that can be misinterpreted for tubing movement. The slant on the calculated downhole dynamometer card results in a gross pump stroke of 129 inches as compared to the actual of 126. Conditions 8b and 8c did not maintain the correct rod string length.

Other than the stroke length difference, the above rod length errors had no other impact on the results of the diagnostic analysis.

MISSING POINTS WHILE DIGITIZING DYNAMOMETER CARDS

The algorithm for the solution of the wave equation requires data of load, position and corresponding time. Modern computer based dynamometer systems store load and position points recorded at equal time increments. Older dynamometer systems that use X-Y plotters can be outfitted with a device commonly referred to as a "point plotter" to provide this data as well. This type of dynamometer produces a dynamometer card such as shown in Figure 9. Since the points on this dynamometer plot are recorded at equal time increments the analyst must digitize each and every point to ensure accurate data is used when calculating the downhole dynamometer card.

To see what the effect of missing a point would be, four runs were made using the actual point plot of Figure 9. The well for Case 2 was 6530 ft deep with a 2 inch plunger. It had a conventional C-640-356-144 unit with stroke length of 144 inches and pumping speed of 8.8 spm. Figure 10 shows the effects of missing points A, B, C, and both B and C, on the downhole dynamometer card. It shows than when using point plot dynamometer cards, missing even one point can result in noticeable downhole dynamometer card distortions. Although missing one point while digitizing may not affect the diagnosis for the well, missing two or more points may result in severe distortions and wrong diagnosis.

In general, errors will increase as the number of missed points increases and the number of recorded points decreases.

CONCLUSIONS

Difficulties with downhole pump card interpretation may be attributable to input errors rather than "strange" downhole conditions. As demonstrated by the example cases, calculated downhole dynamometer cards can not only identify real pump problems but can also help detect errors with load scale, pumping speed, rod string lengths and missing points while digitizing dynamometer cards.

With the information presented in this paper the dynamometer analyst has some additional tools for more accurate downhole pump problem diagnosis.

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5. Svinos, J. G.: "Successful Application of Microcomputers To Analyze Sucker Rod Pumps", SPE 17789 presented at the 1988 Symposium on Petroleum Industry Applications of Microcomputers, San Jose, CA, June 27-29, 1988.

ACKNOWLEDGEMENTS

I would like to thank Chevron Oil Field Research for permission to publish this paper.

Table 1
Effect of SPM Errors on Selected Calculated Parameters for Case 1

Parameter	Correct	SPM+40%	SPM-40%	SPM+20%	SPM-20%
Gross Pump Stroke (in)	126	120	134	123	130
Max. % Rod Loading for Service Factor = 0.9	111%	99%	119%	105%	115%
System Efficiency	39%	28%	65%	32%	48%

Table 2
Effect of Load Scale Errors on Selected Calculated Parameters for Case 1

Parameter	Correct	Load Scale+40%	Load Scale-40%	Load Scale+20%	Load Scale-20%
Gross Pump Stroke (in)	126	143	128	133	124
Max. % Rod Loading for Service Factor = 0.9	111%	210%	50%	153%	77%
System Efficiency	39%	31%	24%	41%	43%
Peak Torque (M In*lbs)	644	1,357	930	986	786

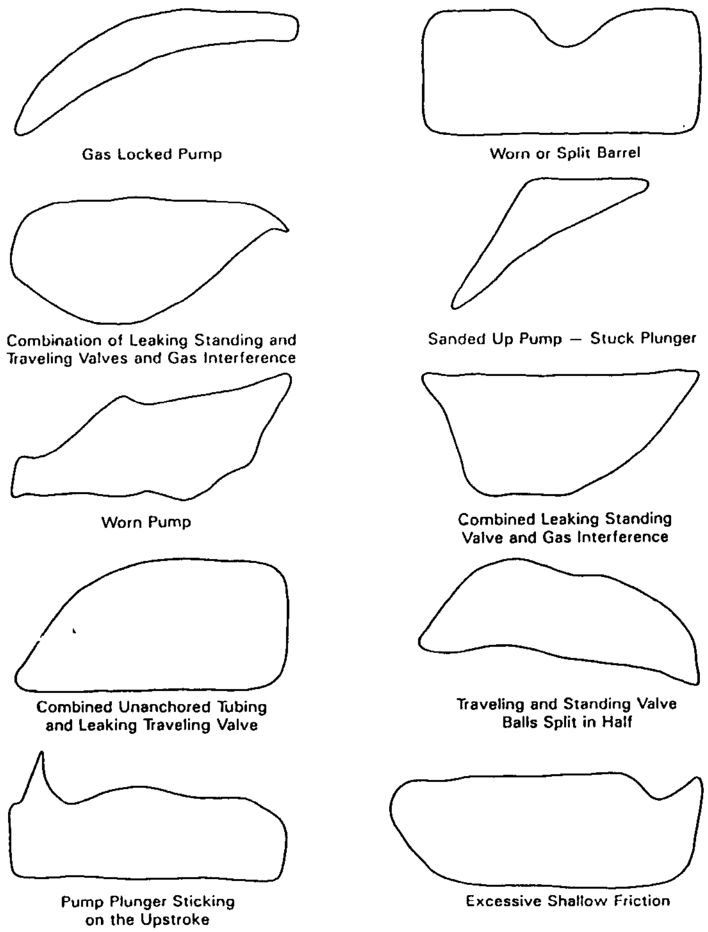

Figure 1 — Examples of verified downhole dynamometer card shapes

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COFRC ROD PUMPING SURFACE AND DOWNHOLE EQUIPM
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LEASE AND WELL NUMBER: CASE 1 (With correct da

COMMENT:

DATE:  11/1/88                         DYNA FILE: H1351B

USER:  J.G. Svinos

PUMPING UNIT: AMERICAN C-640-365-168   ID=A3
STROKE LENGTH: 143.0 INCHES      CRANK HOLE NO.: 2
PUMPING SPEED (SPM): 6.74     CRANK ROTATION: COUNTERCLOCKWISE
RUNTIME: 4.3 HRS/DAY

CALCULATED MAXIMUM COUNTERBALANCE MOMENT (M IN-LBS): 1478.7

SPECIFIC GRAVITY OF PRODUCED FLUID: 0.83
WEIGHT OF RODS IN FLUID: 15817 LBS

PEAK POLISHED ROD LOAD (LBS):    25827
MINIMUM POLISHED ROD LOAD (LBS): 11241
STRUCTURE LOADING: 70.8%

    GEAR REDUCER AND POWER ANALYSIS
    -------------------------------

POLISHED ROD HP:   16.1                  EXISTING      BALANCED
                                         --------      --------
CYCLIC LOAD FACTOR:                         1.94          1.93
RECOMMENDED MOTOR SIZE, NEMA D (HP):        40.0          40.0
DAILY POWER CONSUMPTION (KWH):                81            81

MAX COUNTERBALANCE MOMENT (M IN-LBS):     1478.7        1456.5
COUNTERBALANCE EFFECT (LBS) AT 90°:        20027         19704
COUNTERBALANCE EFFECT (LBS) AT 270°:       18961         18653
MAX NET TORQUE (M IN-LBS):                 644.4         631.3
% OF GEAR REDUCER RATING:                  100.7          98.6

            - - - UNIT IS IN GOOD BALANCE - - -

          * * * GEAR REDUCER IS OVERLOADED * * *
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Figure 2 — First page of SADA output for Case 1

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WELL: CASE 1 (With correct data)   DATE:  11/1/88

CRANK AND COUNTERWEIGHT INFORMATION:
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PUMPING UNIT: C-640-365-168               CRANK: KA-117-53

BALANCED MAXIMUM COUNTERBALANCE MOMENT (M IN-LBS.):     1456.5

EXISTING CONDITIONS:

              MASTER     AUX            POSITION
FRONT LEAD:  N                            3.30
FRONT LAG:   YJ                           7.90

BACK LEAD:   YJ                           8.00
BACK LAG:    N                            2.80

THE UNIT IS IN GOOD BALANCE.  THE COUNTERBALANCE MOMENT
CALCULATED FROM THE EXISTING COUNTERWEIGHT CONFIGURATION
IS WITHIN 2% OF THE COUNTERBALANCE MOMENT FOR BALANCED
CONDITIONS.

ROD STRING STRESS ANALYSIS:
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ROD DIAMETER (INCHES)	LENGTH (FEET)	ROD GRADE	TENSILE STRENGTH (PSI)	MAXIMUM STRESS (PSI)	MINIMUM STRESS (PSI)
1	1845	D	115000	32884	14312
7/8	2125	D	115000	31753	11284
3/4	3750	D	115000	31699	6758
1	502	D	115000	7162	-3640

% ROD LOADING:

ROD DIAMETER (INCHES)	SF=0.6	SF=0.7	SF=0.8	SF=0.9	SF=1.0
1.000	239.1	162.2	122.8	98.7	82.6
.875	209.4	154.1	121.9	100.8	86.0
.750	195.3	155.6	129.3	110.7	96.7
1.000	54.9	48.4	43.2	39.0	35.6

Figure 3 — Second page of SADA output for Case 1

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WELL: CASE 1 (With correct data)   DATE:  11/1/88

DOWNHOLE PUMP CARD ANALYSIS DATA
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PLUNGER DIAMETER (IN) : 1.50     GAS INTERFERENCE          : UNLIKELY
PUMP DEPTH (FEET)     : 8279     OIL PRODUCTION (BPD)      : 27
OIL GRAVITY (API)     : 40.0     WATER PRODUCTION (BPD)    : 8
CASING PRESSURE (PSI) :   65     EXPECTED OIL PROD. (BPD): 27
TUBING PRESSURE (PSI) :  250     NET PROFIT ($/BBL)        : 10.00
BUBBLE P. PRESS. (PSI): 3545     STATIC W.BORE PRESS.      : UNKNOWN
FORM. VOLUME FACTOR   : 1.40     ELECT. COST ($/KWH)       : 0.06

PARAMETERS ESTIMATED FROM PUMP CARD
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PUMP INTAKE PRESSURE (PSI)     :   70    FLUID LOAD (LBS): 5103
FLUID LEVEL FROM SURFACE (FT): 8265    FEET ABOVE PUMP :   14

PUMP DISPLACEMENT BASED ON GROSS STROKE OF 126 IN.:
    AT PUMP (BPD)    :   40
    AT SURFACE (BPD):   37

PUMP DISPLACEMENT BASED ON NET STROKE OF 124 IN.:
    AT PUMP (BPD)    :   39
    AT SURFACE (BPD):   37

PUMP VOLUMETRIC EFFICIENCY (ACTUAL PROD./GROSS PUMP DISPL.): 87.7%

SYSTEM EFFICIENCY AND ELECTRIC POWER COST
-----------------------------------------

SYSTEM EFFICIENCY (MINIMUM ENERGY REQUIRED FOR PRESENT
FLUID PRODUCTION DIVIDED BY ENERGY IN PRIME MOVER)  = 38.7%

ELECTRICITY COST = $   .18 / BBL OIL
                   $   .14 / BBL FLUID
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Figure 4 — Third page of SADA output for Case 1

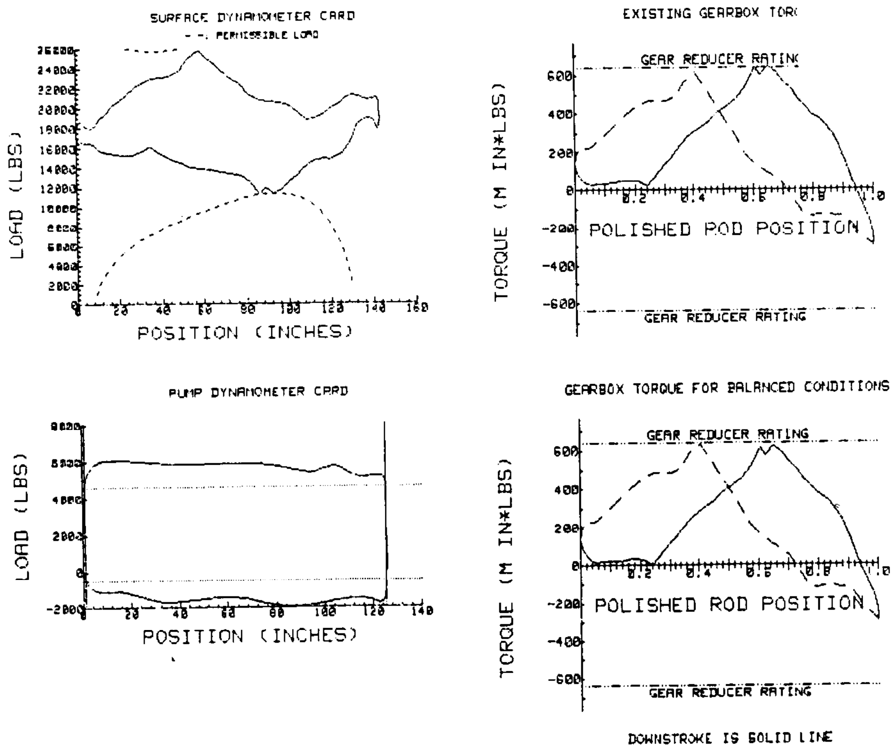

Figure 5 — Fourth page of SADA output
for Case 1

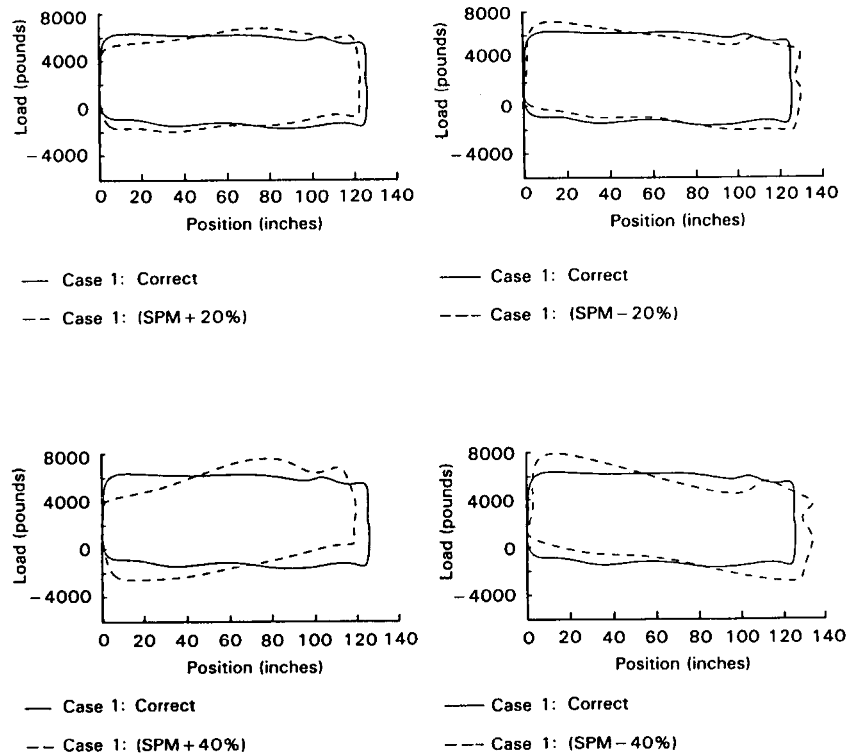

Figure 6 — Effect of pumping speed errors
on downhole dynamometer card

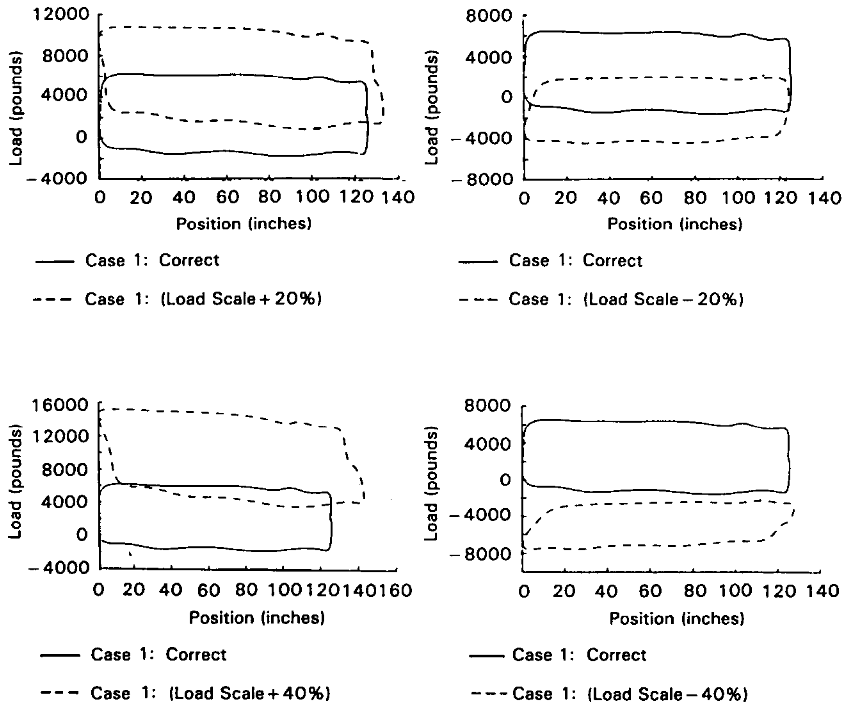

Figure 7 — Effect of load scale errors on downhole dynamometer card

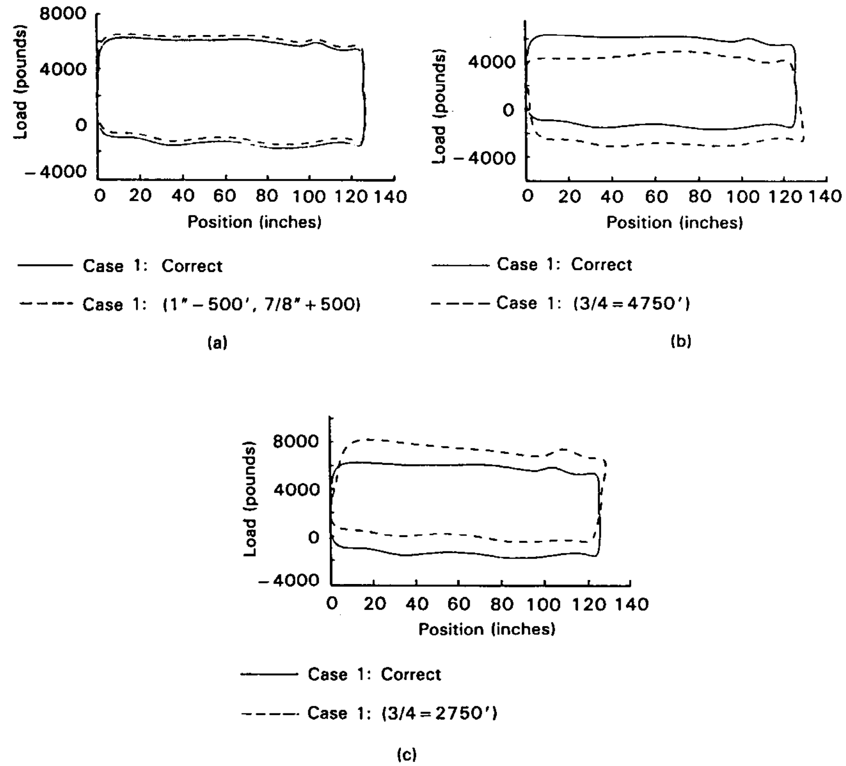

Figure 8 — Effect of rod string length errors on downhole dynamometer card

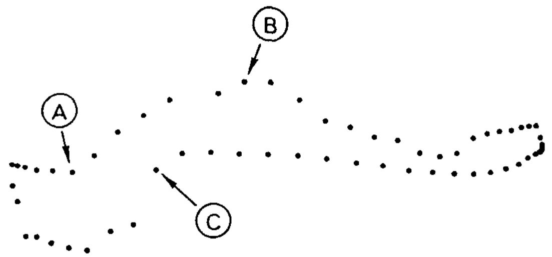

Figure 9 — Point plot dynamometer card for Case 1

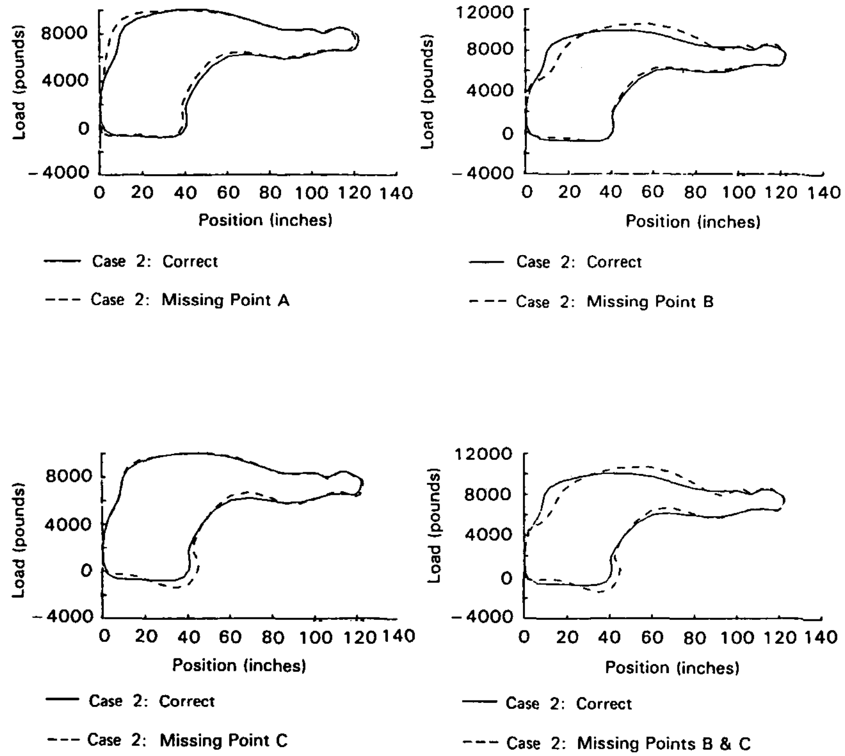

Figure 10 — Effect of missing points while digitizing on downhole dynamometer card