QUALITATIVE LOAD ANALYSIS—A NEW APPROACH TO BEAM PUMP MONITORING AND CONTROL

BARRY S. WELTON and G. WAYNE WESTERMAN
End Devices, Inc.

INTRODUCTION

The major portion of domestic oil is produced by rod pumping systems. Of the total 527,000 domestic oil wells 403,000 are rod pumped. In 1971, $157.5 million was spent for labor and material for downhole repair of these wells. This amount does not include production losses while the wells were being serviced. In that the average pulling job cost was $418.63[1] it is possible that the production losses exceeded this direct maintenance cost. When the total cost for maintenance and the volume of oil produced are considered, it is evident that even a small decrease in maintenance or a small increase in producing efficiency can have a significant economic impact.

This paper considers the development of a new concept for controlling and monitoring rod-pumped oil wells. The development of the hardware and the techniques for implementing the concept are an integral portion of the consideration.

BACKGROUND

Production management personnel for a number of oil companies have recognized for many years that a viable system for their pumping operations would provide economic benefits through improved efficiency and reduced maintenance. Several systems which monitor some portion of the pumping operation have been installed. Flow/no-flow indicators provide an indication of abnormal flow conditions through the flow line which may indicate a starved-pump condition or equipment malfunction. Motor-current measuring systems can be used to detect abnormal pumping conditions which will cause a change in the motor current. Rod loading at a point in the stroke will indicate a starved pump or perhaps a downhole malfunction. Any of these systems when properly applied, installed, maintained and operated will provide improvements in the pumping operation. None of these systems provide direct primary operational data which may be utilized in determining the condition of the pumping system.

A NEW CONTROL CONCEPT

The requirement for primary operational data arose from the application of digital computers to productions automation projects. Through the use of the computer it is possible to process large amounts of data and make control decisions based on the results.

The Midland Division of Mobil Oil Corp. developed the concept of making a waveform analysis of the load-vs-time signal from a rod-pumped well. The basis for the idea lay in the successful application of waveform analysis techniques to solving problems associated with gas chromotography. It was reasoned that manual well analysis is accomplished through the use of a dynamometer which produces a type of waveform and that automated waveform analysis would apply.

HARDWARE DEVELOPMENT

In order to implement the waveform analysis concept it was necessary to obtain loading information from a large number of wells. At that time all load transducers being marketed had a cost or application limitation which rendered them unusable for the task. The decision was made to develop an entirely new load measuring and transmission system. End Devices, Inc. working in close cooperation with Jacque Stoltz and Richard Montgomery of Mobil defined and developed a load measuring system for the specific purpose of obtaining loading information from rod-pumped oil wells. Extensive field testing and "debugging" was accomplished with the help of Mobil and another major oil company.

The design criteria stated that the device should have a long useful life and should be rugged enough to operate in an oilfield environment. The load element would be located on the walking beam of the pumping unit to eliminate most of the danger of damage due to rod parts and handling during servicing the well.

An uncalibrated transducer design was chosen in that calibration capabilities would result in a large increase in the initial cost. It was felt that all desirable control functions could be accomplished by a qualitative approach and that little economic benefit would be derived from absolute load values.

The load transducer, shown in Fig. 1, is the result of this design effort. The transducer is welded to the top flange of the walking beam and measures the strain level in the beam. The strain level in the walking beam is proportional to the polished rod load.

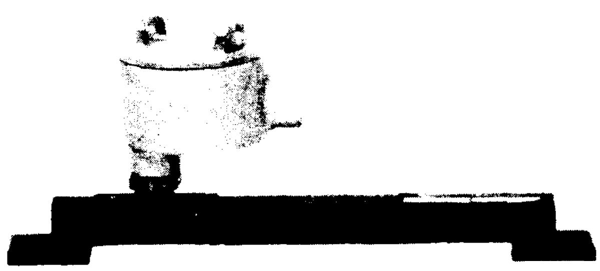

FIG. 1—LOAD TRANSDUCER

LOGIC DEVELOPMENT

When the design of the load measuring system had been successfully completed, development of the logic necessary to analyze the load signal was begun.

The greatest economic benefits were expected from fluid-pound control, equipment malfunction detection and operational supervision. It was anticipated that fluid-pound control would maximize production efficiency by allowing the well to pump only when the pump barrel was filling. The elimination of fluid pound would also reduce the stresses placed on the pumping system due to shock loading, as well as minimize the torque inbalance which occurs during the period when the plunger is free-falling.

The reduction in running time would also reduce power consumption in addition to reducing equipment maintenance.

Early detection of equipment malfunction was considered to be one of the most important functions of the system in that it would allow the operator to repair the defective component and get the well back into production with minimum lost production due to down time. It was projected that the intangible benefits of close supervision of the pumping operation would be significant. It would be possible to obtain daily information concerning such items as secondary recovery response and decreased efficiency in downhole equipment. The examiniation of a large number of dynamometer cards and analog strip charts indicated that the one characteristic common to all wells that pound fluid was an increase in the rate of change in the loading on the downstroke. The dynamometer cards in Fig. 2 show an example of this condition. Card A shows the well pumping with a full barrel. Card B shows the same well in a fluid-pounding condition. Note the differences in the slope of the curve going to minimum load. It should also be noted that the point at which the fluid pound occurs moves progressively to the left of the card or toward the bottom of the stroke. This is due to the fact that the vapor/fluid interface is being lowered in the barrel on each stroke as the barrel fills less on each stroke.

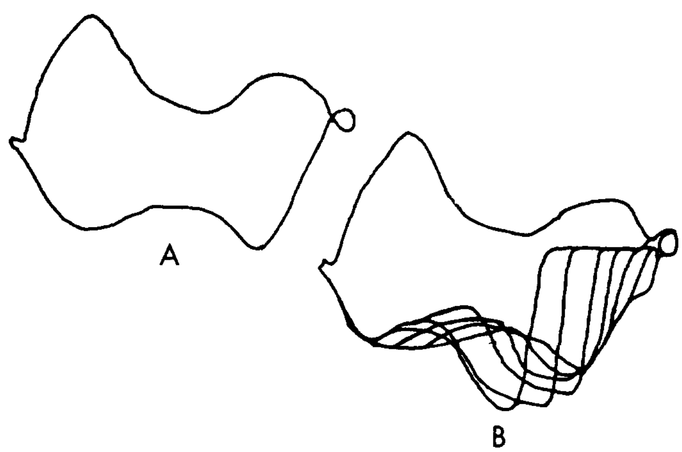

FIG. 2—FLUID POUND

It was also determined that the large majority of equipment malfunctions would cause a reduction in the load range. Figure 3 shows an example of a rod part. Card A shows the well pumping normally with a full barrel. Card B shows the same well with a parted rod string. The maximum and minimum loads are very near the same value because there is no fluid load transfer by the pump valves.

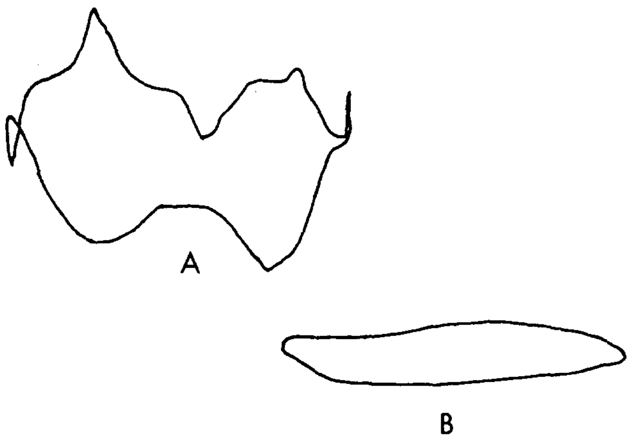

FIG. 3—MALFUNCTION

When the basic logic functions had been defined, concurrent efforts were started to develop digital and analog techniques to accomplish the detection and control functions required. The load measurement and waveform analysis can be applied to the control of oil wells in a number of ways. In some cases individual well control is preferable while in other cases it is desirable to monitor and control a large number of wells from a central point. The flexibility of the concept and the hardware allows economical applications to a wide variety of situations.

Manual Data Collection

The combination of a load transducer, portable amplifier, X-Y recorder, and polished rod position transducer will allow the operator to quickly gather qualitative dynamometer information on a large number of wells. The ability to observe the dynamometer card as it is being drawn can be a great assistance in evaluating the pumping condition. The rig-up time for the system is very short—one to two minutes. The major limitation to the quantity of dynamometer information that can be gathered in a period of time is the transportation time between wells.

Local Analog Control

Local analog control is applicable to isolated or small numbers of wells. The control logic is accomplished by analog electronic circuitry which measures the rate of change of the load and the load range. The circuitry assures that the well has stablized in abnormal condition and performs the appropriate control and/or alarm function. In the case of fluid pound, the pumping unit is shut down and then restarted after a preset down time. If an equipment malfunction is detected, the pumping unit is shut down and an alarm is provided. The unit must be restarted manually.

A run time accumulator records the amount of time that the unit is in operation. The daily run time is very useful in detecting increases in fluid production or loss of pump efficiency.

Direct Digital Supervisory System

Direct digital supervisory control provides more flexibility in the control operation in that any operating parameter may be changed at the central control console. In addition, all operating information can be made available in written form through print-out equipment. Direct digital supervisory control is applicable to large numbers of wells which are concentrated geographically and are to be controlled in conjunction with other supervisory functions such as well testing and injection well monitoring.

The control logic in the digital supervisory system is accomplished by a central digital computer. The load data is transmitted from the well to the computer through a digital communication system. The communication rate of the system must be fast enough to provide adequate data for the analysis of the number of wells in the system.

The control system composite is shown in Fig. 4.

Hybrid Computer Local System

The hybrid computer/local system combines the functions of the local logic system and the digital control system. The load signal analysis is accomplished by the analog electronics and the results are transmitted to the computer through a digital communication system in the form of status indications. The computer in turn may control the operation of the well by sending control signals to the well through the communication system and the interface relays at the well. In that the information transmitted takes the form of

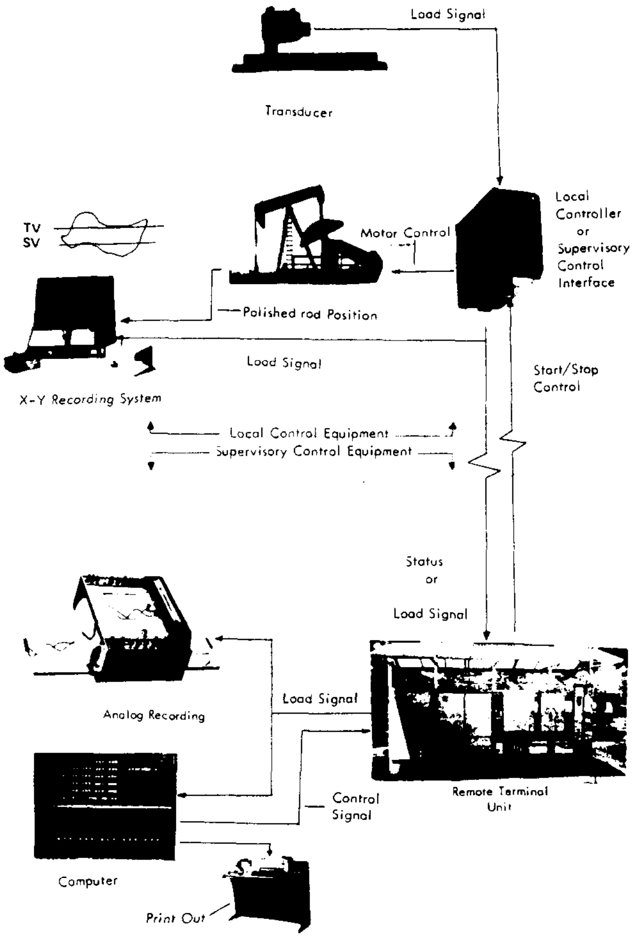

FIG. 4—CONTROL SYSTEM COMPOSITE

status points, the rate requirements on the communication system are much lower than in a direct supervisory system.

In most cases, the system is arranged in such a way as to allow the control to revert to local mode in the event of any malfunction in the supervisory system. Upon clearing the fault in the system, the remote control of the well is automatically resumed.

One of the benefits of the hybrid system lies in the capability of installation and operation of the well control equipment while the remainder of the supervisory equipment is being designed, built, and installed.

APPLICATION USING API BUL 11L2 CARDS

The comparison of a qualitative dynamometer card produced by the deflection of the walking beam with the API computer curves offers a fast and convenient approximation for establishing whether or not the beam pumping well is operating within accepted standards. As stated in the bulletin,[2] "all of the dynamometer cards were taken under conditions which simulated full filling of the pump barrel. There was no fluid or gas pound. Therefore, the card shapes are representative of good bottomhole pumping conditions. Deviations in shape of cards occur when wells are pounding fluid or when pumps are handling gas or for other reasons such as plunger sticking, tubing buckling, excessive paraffin deposits, worn plungers, leaking valves, etc." Confirmation of a full pump barrel shape in the field is the object of the comparison. It is again emphasized that we are not concerned with absolute loads; other devices are available for measuring absolute loading and should be used when desirable.

The validity of the approach is shown by Figs. 5 and 6. Field cards are compared and examples shown of good pumping conditions and abnormal conditions. Figure 7 predicts the X-Y plot for various pumping conditions for a single taper string and 5% motor slip. These API cards have been rearranged and contoured to show the effective bottomhole stroke length which is a measure of pumping efficiency.

Since the cards are indexed under N/N_0 and F_0/SK_r, a method to rapidly approximate these numbers is shown in Fig. 8. N/N_0 = SPM (pump depth)/245,000 and the nomograph assumes the rod frequency factor is one. This is true only for nontapered rod designs; however, the number will be within 10% in most design situations.

Nomographs were constructed for F_0/SK_r for different pump sizes assuming a specific gravity of one and an elastic rod constant of one. A correction factor for two taper strings is also shown. The nomograph is based on the following formula:

$$\frac{F_0}{SK_r} = \text{(pump load factor x specific gravity x fluid level x pump depth x rod elastic constant)/(stroke length)}$$

The F_0/SK_r nomograph is based on the fluid level being at the pump. If this is not the case and the fluid level is known, then an average depth based on fluid level and pump depth should be used.

The pumping example shown in Fig. 8 was taken from the Bethlehem Steel Handbook.[3] This is thought to be a good example because the pumping speed was varied and dynamometer cards taken for each condition. Let's work through the example.

Two N/N_0 factors are obtained from the nomograph for a pump depth of 3300 ft and varied pumping speeds of 17.5 SPM and 22 SPM. As can be seen, these factors are 0.23 and 0.30 respectively.

F_0/SK_r is read from the nomograph as 1.6 and multiplied by the elastic rod constant of 0.6 to get a factor of 0.10.

By knowing the above factors, the field dynamometer cards can be compared with the API cards shown in Fig. 8.

SUMMARY

The intent of this paper is to direct the reader's thoughts more keenly toward the goal of reducing direct maintenance costs and increasing the system efficiency of his beam pumping operation. A small percentage savings of the $157.5 million spent in 1971 is well worth the effort. It is thought that the methods mentioned herein present a logical and economical approach toward that end.

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2. API Catalog of Analog Computer Dynamometer Cards, API Bul 11L2, First Edition.
3. Bethlehem Steel Company, "Sucker Rod Handbook:" Handbook No. 336.

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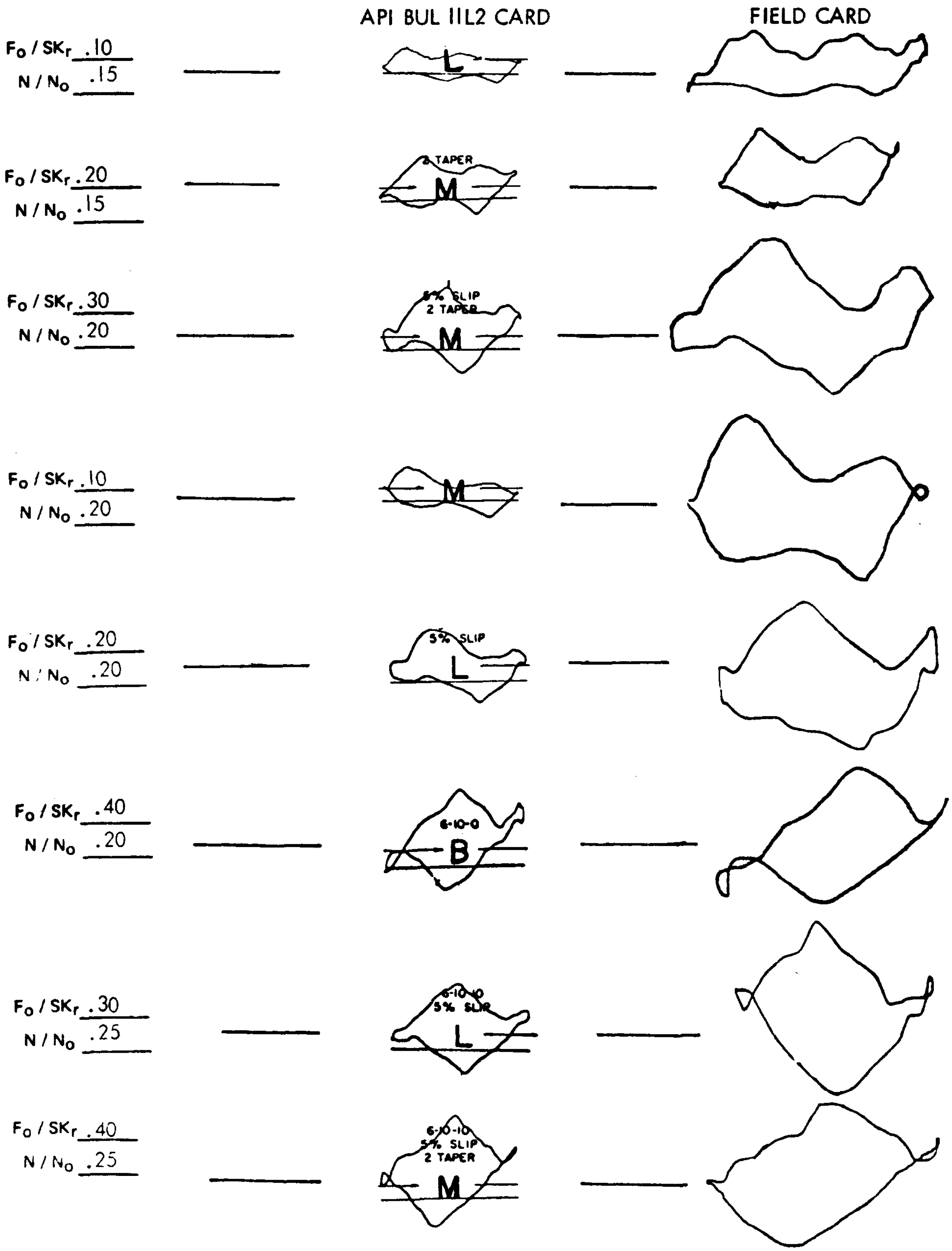


FIG. 5—COMPARISON OF API CARD WITH FIELD CARDS

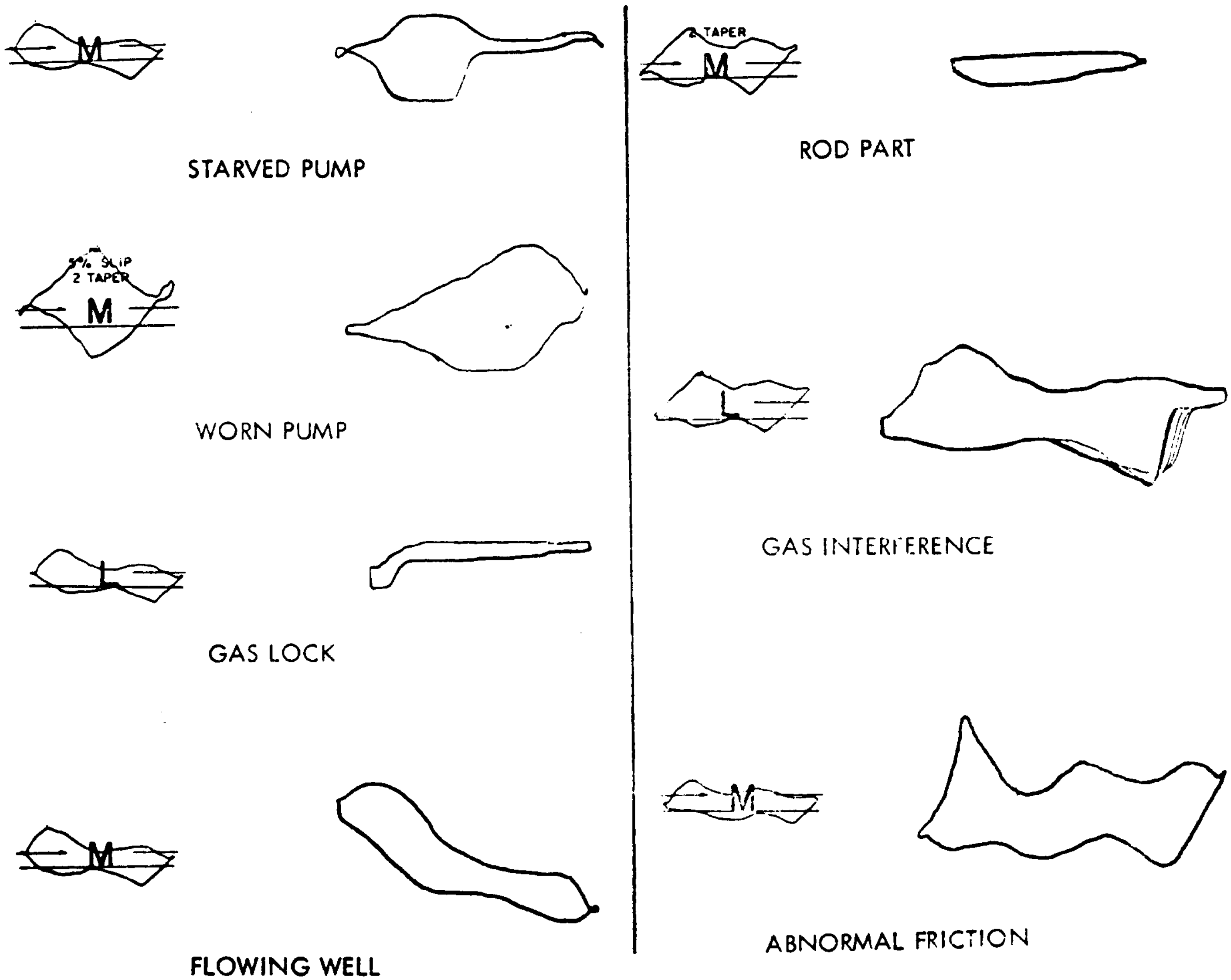
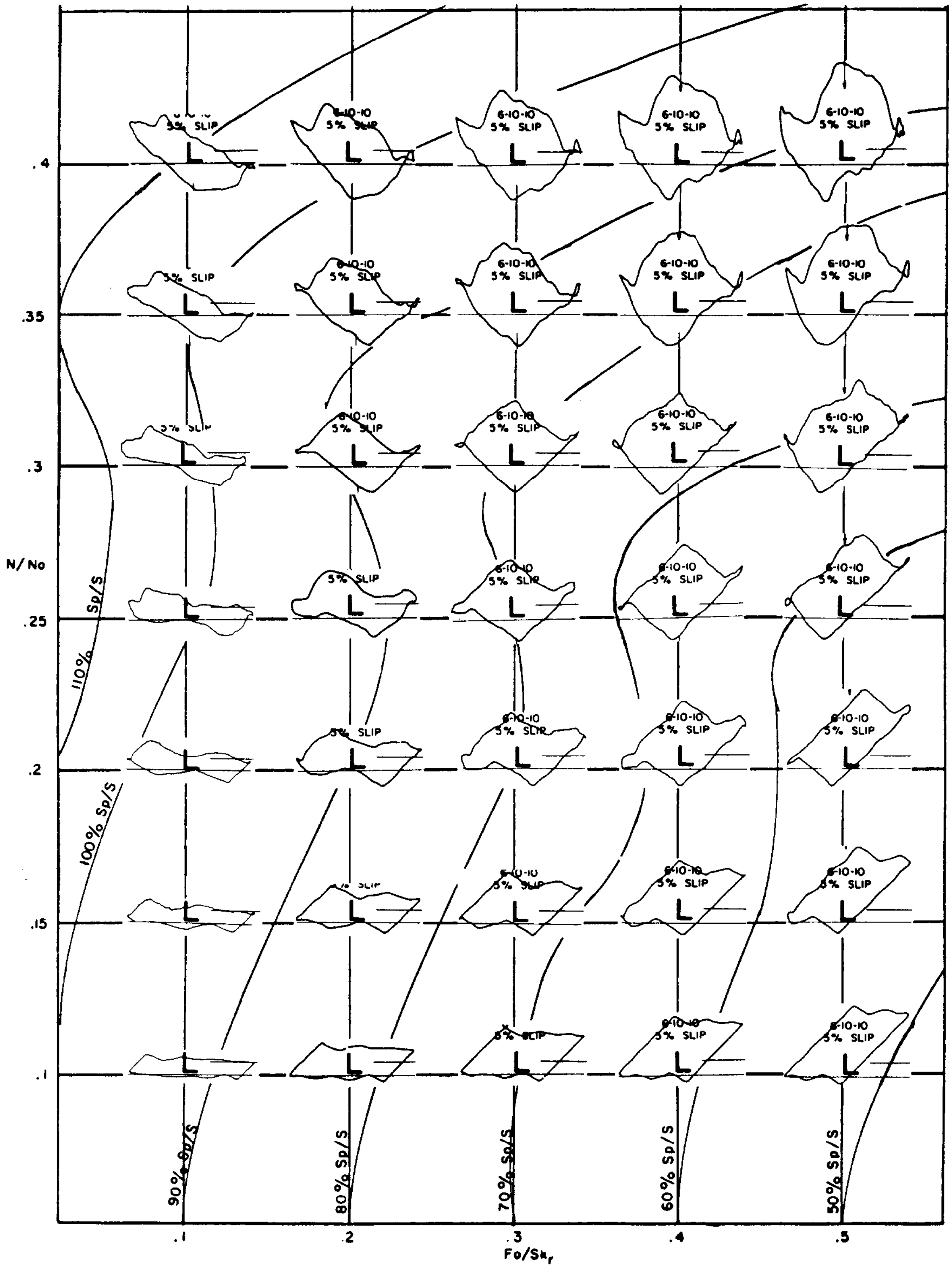


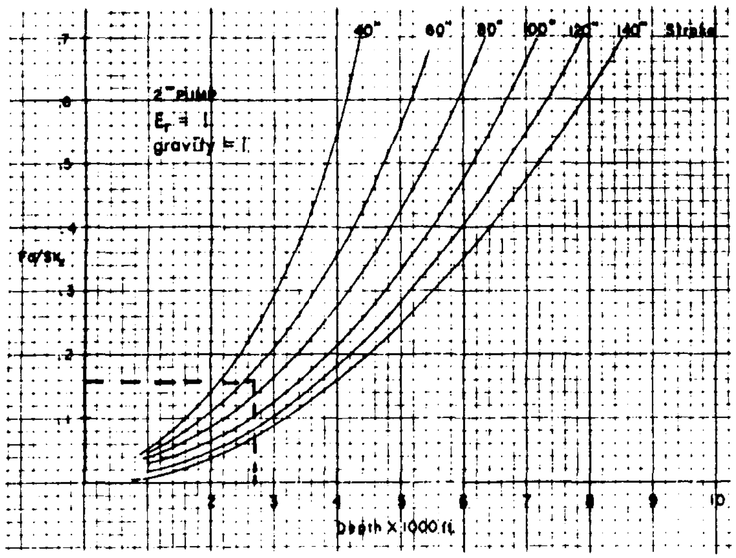
FIG. 6—COMPARISON OF API CARD
WITH ABNORMAL FIELD CARDS



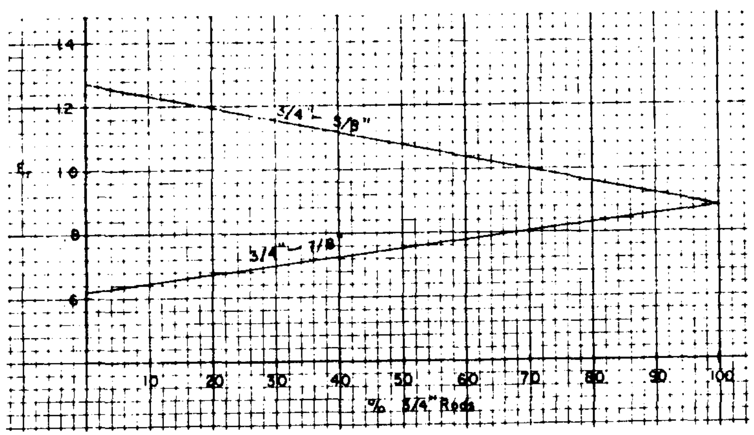
API BUL 11L2 DYNAMOMETER CARDS
SINGLE TAPER 5% SLIP

N/N_O VRS. F_O/SK_r AND S_P/S

FIG. 7

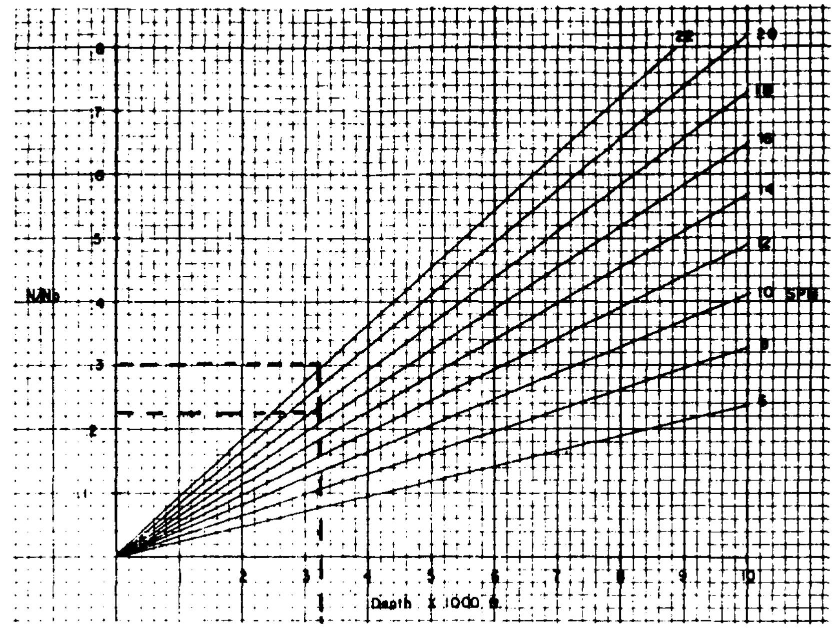


F_o/SK_r NOMOGRAPH

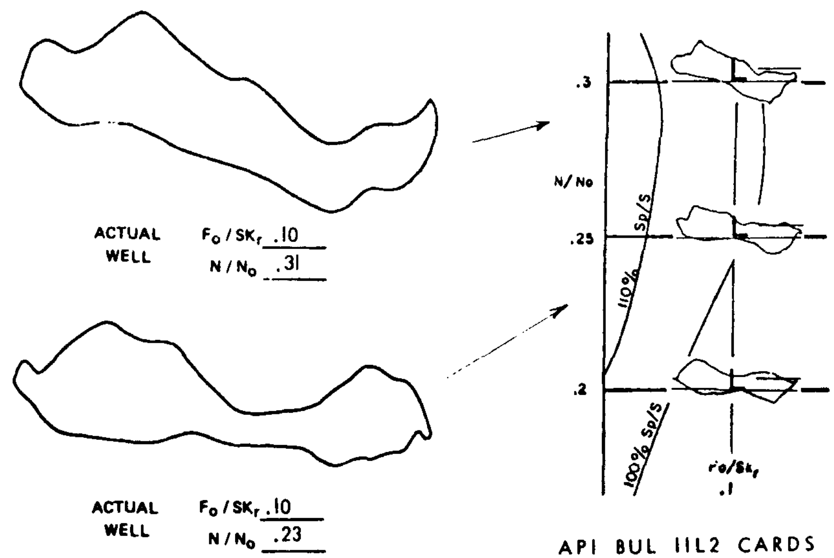


E_r NOMOGRAPH TWO TAPER

well information:
100% 7/8 rods
64" stroke
spm varied from 17.5 to 22
2" pump
average depth 2700'
pump depth 3300'



N/N_o NOMOGRAPH



API BUL 11L2 CARDS
SINGLE TAPER 5% SLIP

FIG. 8