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Development of a System to Display and Record Slack Action in Freight Trains

Transportation Systems Center, Cambridge, Mass

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DEVELOPMENT OF A SYSTEM TO DISPLAY AND RECORD SLACK ACTION IN FREIGHT TRAINS

J.D. Vrabel
E.D. Sussman
D. Ofsevit

U.S. Department of Transportation
Transportation Systems Center
Kendall Square
Cambridge MA 02142

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16. Abstract

This report summarizes the development of a system which senses, displays and records the slack action or inter-car movement in freight trains. The system, called the Draft-Buff Indicator (DBI), was developed to serve as a train-handling aid. It provides the user (railroad training officer, accident investigator or locomotive engineer) with a real-time display of the draft-buff distribution within a moving train and also provides a record of the information for later analysis. The report discusses the development of the sensors, transmitters, receivers and display which make up the system, as well as alternative versions of the system which were considered and rejected for various reasons. The report also discusses the various applications of the system in revenue service and in accident analysis up to the time of publication.

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PREFACE

The work described in this report was performed as part of TSC's work in train handling, under the sponsorship of the Federal Railroad Administration and in cooperation with the International Government-Industry Track-Train Dynamics program, Task Four. The following people assisted by providing technical and practical suggestions, access to railroad properties for testing, and aid in conducting experiments.

Association of American Railroads: E.F. Lind

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Southern Pacific Transportation Company: D.D. Grisson, R.D. Pigg, E. Thomas, and R. Austill.

The following individuals made significant technical contributions to the DBI at the Transportation Systems Center: D. Gosselin, C. Hoppin, J. Owens and A. Wichansky.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
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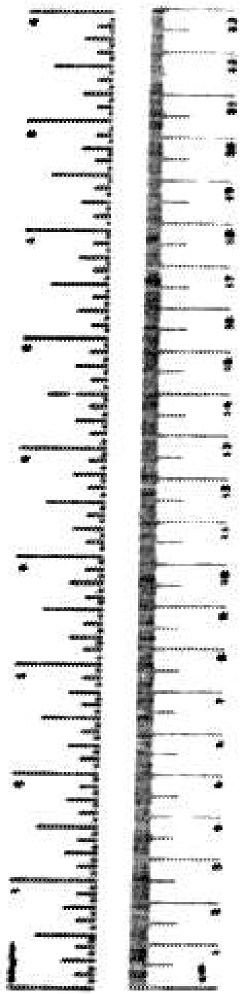

Approximate Conversions from Metric Measures

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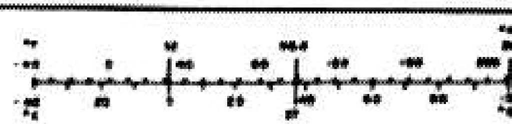

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1. INTRODUCTION

1.1 BACKGROUND

The Transportation Systems Center (TSC), under the sponsorship of the Federal Railroad Administration's Office of Research and Development, has developed a train-handling aid called the Draft-Buff Indicator (DBI). The development occurred during Phase I of the cooperative Government-Industry Track-Train Dynamics (TTD) program. The purpose of this aid is to monitor, display and record the slack action of the train. The slack motion needed between cars for proper train handling allows the coupling extensions to exist in either of two states: (1) buff, or bunched, with forces pushing the cars against each other, and (2) draft, or stretched, with forces pulling the cars away from each other. The DBI can display to railroad operating or research personnel, in real time, the draft/buff conditions of serveral selected couplings in the train. One can also record the DBI information on an ordinary cassette recorder for later playback and analysis.

1.2 USE OF THE DBI

Using the DBI, one can determine the following:

- Whether the entire train is stretched, bunched, or mixed.
- Whether slack action is occurring, and where it is occurring.
- Where terrain-induced inter-car motion occurs.
- The approximate location of the power node* in helper operations.

Such information should be useful for:

- Starting a long train.
- Dynamic braking (using the electric traction motors to dissipate energy) on long grades.
- Operations involving changes in grade, particularly on undulating terrain.
- Helper operation.

*The approximate location in the train where the influences of the leading and trailing power consists are equal.

Anticipating the effects of run-in or run-out (violent car shock caused by sudden draft/buff state changes).
Planning future train-handling strategies.

One can use the DBI information to develop train-handling strategies to reduce or eliminate large force changes between cars, whether caused by throttle and brake changes or by difficult terrain. The resulting improved (smoother) train operation should reduce damage to track, rolling stock, and freight. Smoother handling can also help reduce the number of train accidents, such as derailments or break-in-twos.

2. DBI OPERATIONS

2.1 SYSTEM CONCEPT

Figure 1 illustrates the basic concept of DBI operation. A freight train can be divided conceptually into N + 1 blocks of freight cars. The blocks need not be of equal length, and the average block length depends on N and the total length of the train; this allows the user to measure coupling extension at the points most representative of the train dynamics or at points chosen to suit needs of a particular investigator. At each point between blocks is a sensor (Si) which measures the inter-car distance and indicates the condition, buff or draft. Each Si activates an encoder (Ei) which controls an individual radio transmitter (Ti). In the locomotive, a radio receiver receives the signals from all the transmitters. The output of the receiver goes to a decoder which operates a display that one can view and interpret.

Figure 2 represents the DBI display. For each Si there are two display lights (Di, Bi). Activation of Di indicates a draft state, Bi indicates a buff state. If neither light of a pair is lit, the user can assume that the radio has not received the most recent transmission from the corresponding transmitter.

The system developed at TSC has used 5 coupling state detectors throughout its development. A smaller number would degrade system resolution; the blocks of freight cars in Figure 1 would be so large that the inter-lock sensors would be likely to miss many significant train actions. Even with 5 sensors a block can contain over 30 cars in a long train. The logistic problems of mounting the sensors along the train prevented the use of more than 5 per train; once a train has been made up in a yard, the yard personnel usually wish to attach the engines and dispatch the train with very short notice and at their convenience. With 5 sensors, the process of securing the track, walking or driving the length of the train, attaching the sensors, and notifying the appropriate yard official can occupy 15 minutes to a half hour or more. Even this short period is often inconvenient to the railroad.

2.2 DEVELOPMENT OF THE DBI SENSOR

2.2.1 Initial Considerations

From the beginning, the most difficult problem in DBI development has been the method for determining the physical state of a coupling. Cost and complexity considerations ruled out the use of sophisticated techniques, including inductive or capacitive displacement transducers, or microwave or acoustical reflection techniques. Development efforts were concentrated on simple electromechanical techniques, so that the sensors could be inexpensive, rugged, and easy for non-technical people to install. The following major problems were encounterd and dictated the order of the development process:

Despite the constraints upon the relative movements of railroad cars, there is enough freedom of movement in the couplers, draft gear, and suspensions to allow a car to move several inches in any direction with respect to its neighbors.

The average change in inter-car distance between draft and buff can vary from as little as 2 inches in tight unit trains with new couplers, through 10 inches for average freight cars, to several feet for cars with hydraulically cushioned draft gear.

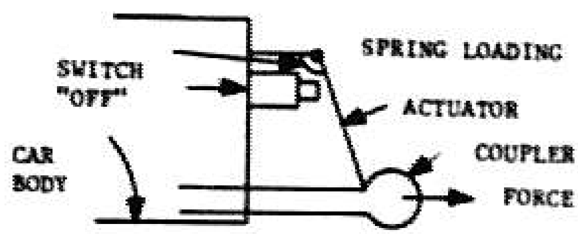
Coupler wear greatly affects relative inter-car motion.

A sufficiently violent force can change the "operating point" of a coupling, so that a given inter-car distance can mean draft at one time during a trip and buff at another.

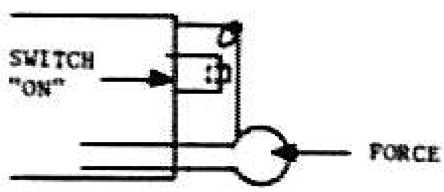
2.2.2. Early Prototypes

2.2.2.1 Sensor Switch Between Coupler and Car Body

Figure 3 shows the original sensor used on the first DBI on-board tests. The design of this sensor assumed that in draft the coupler knuckle would be relatively far from the car body:



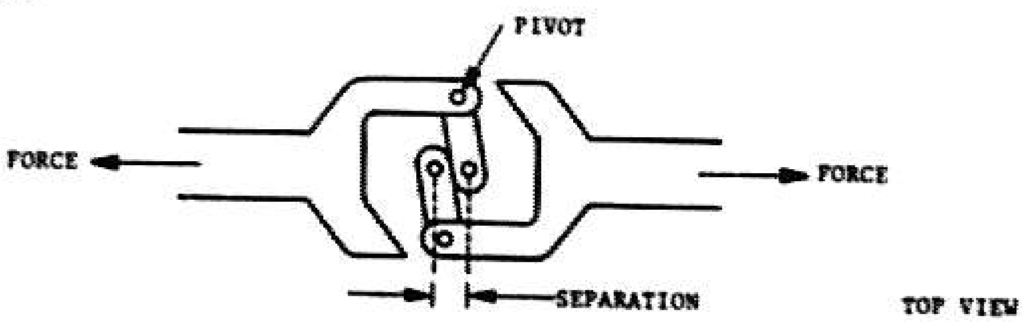
While in buff the coupler would be closer:



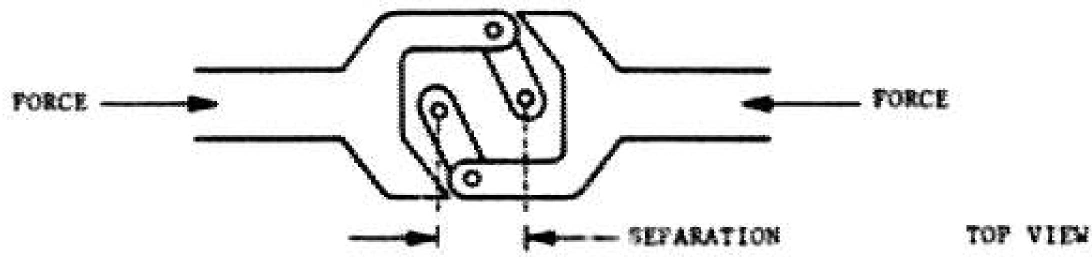
The bracket holding the switch and actuator arm was welded to the car and the actuator arm bent to set the switching point. This design was satisfactory once the sensor was calibrated to the particular coupler, but the calibration and mounting procedure was not feasible for regular use. The sensors had to be welded to the cars and, once mounted, individually calibrated.

2.2.2.2 Sensor Attached to Coupler Knuckles

The next sensor configuration considered used the casting holes in the coupler knuckles. In draft, the holes move close together:



In buff, the holes are farther apart:



The locations of the casting holes were measured with threaded metal rods inserted through the holes. The mounting scheme used folding toggle wings to secure the rod and spring tension to hold it steady.

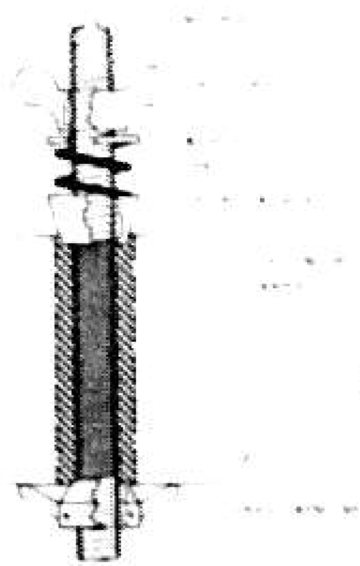


Figure 4 shows this scheme in actual application. The mounting and demounting was simple and fast. As a rod was pushed through a casting hole, the spring compressed until the toggle wings emerged from the lower end and flipped open. The spring tension acting on the expanded wings fixed the rod vertically. The tapered washer and the machined taper on the toggle wing nut kept the rod centered in the hole. For removal, the rod was rotated with a wrench at the notched flats at the upper tip of the rod. The toggle wings, which were inexpensive enough to be expendable, unscrewed and fell to the ground. The rod could then be pulled up and out of the hole.

The device for detection of the distance between the two rods was self-adjusting. The upper half of one rod was machined smooth. Attached to the other rod was a platf rm with a slot through which the smooth rod moved. (See Figure 4.) The slotted platform had a series of triangular teeth machined in its upper surface which meshed with similar teeth on a smaller slider piece. Springs on the attaching bolts forced the teeth into engagement. The shape of the teeth allowed the slider to move back toward the closed end of the slot, but only under sufficient force to overcome the spring tension holding the teeth together. Only another large force in that direction could move the slider again.

The buff/draft detector was a microswitch mounted on the slider. In buff, the casting holes moved apart, so that the smooth rod moved toward the open end of the slot and the switch was open. In draft, the holes moved together and the smooth rod closed the switch. If the slider had not originally been set for a "tight" draft condition, the smooth rod would force the slider to move toward the closed end of the slot to the proper setting.

This arrangement worked well on some couplings but poorly on others. On some worn couplings, the knuckles would rotate in buff until the casting holes were as close together as in draft. On other couplings the knuckles would tend to lean away from the couplings and make the rods non-parallel if the coupling state was not tight draft or buff. The length of the rods above the knuckles had the effect of magnifying this phenomenon and giving false buff/draft readings. These problems were further exacerbated by the relative vertical coupler motions which, when the rods were not parallel, appeared as false changes of distance. Although this method was rejected for these reasons, the casting-hole mounting technique may be useful for other future applications.

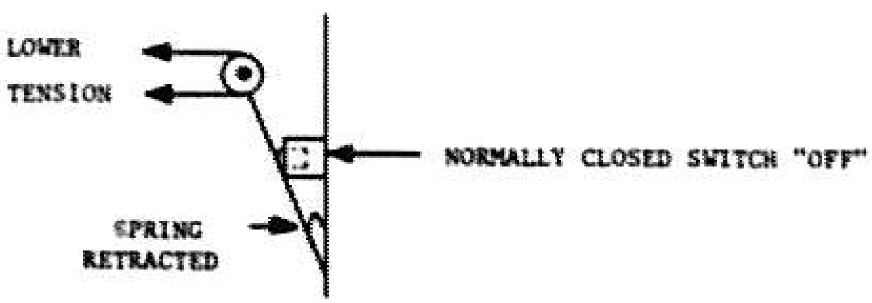
2.2.2.3 "String Puller" Sensor

After a series of field tests and observations, it became apparent that no arrangement using a switch to indicate draft or buff directly would work reliably. The designers turned next to linear position transducers of the "string puller" type, which convert measured distance to a proportional electrical signal. The usual configuration of such a device is a rotary multiturn potentiometer with a string or cable wrapped around the shaft. Pulling the string rotates the potentiometer and changes its resistance. An attached spring motor keeps the string in constant tension.

Forms of the string puller have existed for a number of years and have had various technical applications, but none commercially available could be used directly to measure draft/buff conditions. The DBI is basically a digital device; its outputs indicate coupling conditions in one of two discrete states. Its input, however, is an analog (continuous) function, the distance between cars or parts of the coupling. The switch devices described in Section 2.2.1 and 2.2.2 failed for just this reason. Those devices could not accommodate the complexity of the inter-car distance function. A system using a string puller would obtain the analog value of the inter-car distance and use it to determine buff or draft.

How to make this determination was the basic problem in using a string puller as the DBI sensor. The displayed state must give the user accurate information, but it must be displayed so that it does not overwhelm him with rapid fluctuations indicating every minute change in the inter-car distance. To determine the appropriate type of display, TSC made a number of tests on short local CONRAIL freight trains. Measurements were made between the caboose and the last freight car, where the greatest slack action occurs. The caboose is light and is rarely in tight draft or buff; it tends to "float." The strip chart records (Figures 6, 8, and 9) show the actual inter-car distance (track no. 1 on each chart) along with the responses of the string-puller-based sensors that were tested. Some of the buff/draft decisions are straight-forward; the problem was how to represent the values that lie between hard buff and hard draft.

Figure 5 shows the first string-puller-based device tested by TSC. It had two reels, one a spring-loaded take-up reel and the other a fixed-drag supply reel. It was self-adjusting, operating in the following manner. When first installed, all the string was on the supply reel (the upper reel in Figure 5). As the string loop extended, it unwound string from the drag reel. The first maximum draft would establish the total string unwound from the supply. When the inter-car distance decreased (to floating or buff) the take-up reel would take up the excess string. The string loop went around a small pulley on the car opposite the reels. The pulley was on a spring-loaded pivot controlling a micro-switch. In draft, the take-up reel would be empty and the supply reel would establish tension in the string, activating the switch: In buff, the take-up reel would take up the slack at slight tension, allowing the spring-loaded arm to de-activate the switch:



The device thus "favored" buff; any movement greater than one inch from full extension of the string (full draft) was coded as buff.

This approach had two problems. An illustration of the first problem appears near the end of Figure 6 on track No. 4. During the first part of this test, the switching point was properly set, distinguishing between normal draft and buff or floating. Near the end there was a large draft force resulting in a larger draft extension than any previous ones, taking more string from the supply reel and resetting the buff/draft comparison point. The device now could only distinguish extemely tight draft conditions from all other conditions. This becomes apparent through examination of the very end of the chart, where the device failed to detect an obvious draft condition. It is possible that the change in the comparison point was due to a large draft force or happened when the train went around a sharp curve, as the device in this run was not directly over the coupling and was therefore sensitive to angular and vertical changes as well as to the desired longitudinal motions. The fact remains that, whatever the cause, a single unusally large extension could set the device to an incorrect comparison point. A comparatively minor problem, which did not appear in this example, was jitter around the comparison point. There was a good deal of vibration, but it was properly not detected. Since vibration was not serious in the worst possible position (on the caboose), it would have had even less effect on heavy cars near the middle of the train, where movements would be less prone to jitter.

The string puller device was analogous in many ways to the coupler-knuckle separation device described in Section 2.2.2.2. In fact, it was rejected for similar reasons: it was self-adjusting in one direction only and it had a single comparison point. Again, although the method turned out to be unsuitable to the DBI application, measurement of inter-car distance proved superior to any measurement scheme involving coupler knuckles. The self-adjusting distance-measurement technique may be useful for applications in less vigorous environments.

2.2.3 Final Sensor Configuration: String Puller Sensor with Hysteresis

Based on the experience gained with earlier prototype sensors, a modified string-puller arrangement was designed as shown in Figure 7. It contains a single-turn potentiometer with a slip-clutch shaft and an attached spring motor. As the string is pulled out, the potentiometer turns in one direction to its limit; the clutch then slips and more string can be pulled out without turning the potentiometer farther. When the string extension decreases, the spring motor turns the shaft in the opposite direction to take up slack. The potentiometer rotates as well until it reaches its other limit; the clutch then slips and allows the spring motor to continue taking up slack. The length of string required to turn the potentiometer between its limits can be adjusted by changing the mechanical gear ratio between the string take-up shaft and the potentiometer slip-clutch shaft.

The slip-clutch arrangement allows the sensor to be self-adjusting and readjusting in both directions. Any extraneous overtravel caused by extreme car or draft gear motion can cause a temporary error, but the next full motion in the opposite direction will correct it. Consider a coupling in normal draft, with the potentiometer at its draft limit. A large draft force would pull the string out farther, with the clutch slipping. A return to normal draft would allow the device to take up slack and give a false buff reading, as the potentiometer would be free to move toward its buff limit. However, the next true buff situation would result in the spring motor's taking up more slack, and the buff reading would now be true.

There is a trade-off involved in selection of the length of string movement corresponding to full rotation of the potentiometer (without clutch slippage). Some tightly coupled unit trains have only a few inches of free motion between cars, where too large a string movement between stops would never establish firm buff/draft values and would be insensitive to moderate changes. Too short an allowable string extension on cars with large coupler motion, on the other hand, would yield too many false readings. Field testing has established 4 inches (10 cm) of string motion between stops as satisfactory for most freight cars with standard draft gear. For cases where smaller movement is necessary, the device has been modified in the field.

The sensor's output is a voltage proportional to the position of the potentiometer with respect to its endpoints. A voltage V applied across the input to the potentiometer yields an output in the range 0 to V across the output, with full buff = 0 and full draft = V. Electronic circuitry monitoring this voltage determines the meaning (buff, floating, draft) for the transmitter to send.

Figure 8 shows a method to obtain maximum information from the slip-clutch sensor. The chart covers the same test (train and territory) as Figure 6; the analog string-puller channel (No. 1) is the same for both charts. Figure 9 is an expansion of part of Figure 8. On both Figure 8 and 9, channels No. 3, 4, and 5 show the separate draft, floating and buff determinations. The assumptions used to make these determinations were:

Voltage	Position of Potentiometer	Determination
0-0.25V	Within 1 inch of buff	Buff
0.25-0.75V	Not within 1 inch buff or draft	Floating
0.75-1.0V	Within 1 inch of draft	Draft

(This is shown in detail on Figure 9.) It is obvious on the charts that under certain conditions, such as use at the caboose which floats and shifts often, there is so much information that the user would be confused. This would not be so apparent in the middle of a long, heavy train, but this method may generate more information than desirable. Also, transmission and display of three states would increase data-channel requirements.

A second slip-clutch string puller determination method is shown on Figure 6, channel No. 3. It uses the same definitions for the values 0-0.25V (buff) and 0.75V-1.0V (draft) as above. The middle range 0.25V-0.75V is redefined as hysteresis area; it is whichever condition the sensor was in before entering the range. For large changes, full buff to full draft or vice versa, the sensor operates as expected. For changes from buff to floating or draft to floating, it shows no change until the coupling passes entirely through the 0.25V-0.75V area to the opposite state. This scheme acts as a filter, ignoring the small motions and adjustments which continually occur in couplings, and detecting only major buff/draft transitions.

2.3 DBI RADIO-TELEMETRY SYSTEM

Development of the DBI radio-telemetry link between the coupling sensor and the cab display was more straightforward than that of the sensor. The requirements for the radio-telemetry system were:

> The transmitter packages must be small, light, easy to mount and remove, and sturdy enough to withstand the most extreme environmental conditions encountered on freight trains.
>
> The packages must be battery-operated with power requirements low enough to avoid frequent replacement or recharging.
>
> Tuning should be non-critical; the units must not require frequent adjustment.
>
> The display should show the present state of each sensor, updated immediately whenever a sensor changes state.
>
> If radio contact with a given sensor is temporarily lost, the display for that sensor should be turned off until contact resumes. The user should receive no information when there is a change of false information.

2.3.1 Tone-Encoding DBI Information

A DBI system with N sensors has 2^N different coupler states (draft or buff at each) about which the radio-telemetry link must carry information from the sensors to the display. For simplicity, the entire system uses one carrier frequency, so the draft/buff information is transmitted by modulating the signal with one of 2N different tones. For the 5-sensor system, the following audio-range tones are used:

Station	Draft (Hz)	Buff (Hz)
1 (nearest locomotive)	1127	1025
2	1364	1240
3	1560	1500
4	1996	1815
5 (nearest caboose)	2415	2196

Using audio frequencies allows the signal to be recorded on a standard cassette tape recorder if later laboratory analysis is desired.

2.3.2 Transmitter

The DBI transmitter was designed to send information on the coupling state as required, while using minimal power. The actual radio transmitter, which uses far more power than the rest of the package, usually operates only once every 10 seconds for a period of 0.15 sec. If a change in coupling state occurs of course, a similar short transmission takes place immediately. This coupling-state-change transmission insures that the display shows draft/buff changes as they occur; the every-ten-second transmission confirms radio continuity and provides new information only if the primary transmission is missed.

Figure 10 shows the details of the DBI transmitter. The hysteresis comparator provides draft/buff information about the sensor, as described in Section 2.2.3. A state change causes the flip-flop to set or reset; either action in turn triggers the either-edge "monostable" circuit. This can trigger the transmit-on monostable, which holds the transmitter on for 0.15 second as described above. The flip flop also causes the two-to-one multiplexer control to select the appropriate audio frequency (corresponding to draft or buff) from the two high-frequency free-running crystal oscillators. The select frequency is divided to reach the desired audio frequency; then the low pass filter and wave shaper remove the higher-order harmonics of the square wave. The resultant sine wave is the audio input of the radio transmitter. The transmitter itself is a standard commercially available narrow-band FM "walkie-talkie" set.

2.3.3 DBI Receiver

The DBI receiver incorporates a straightforward means for decoding the incoming signals. The demodulated audio signal must be one of the 2N tones used in the system; otherwise it is rejected as spurious. If it is acceptable, it will cause an appropriate circuit to display the coupling state. If no signal, buff or draft, is received from a given coupling transmitter for 20 seconds (2 update periods), the receiver turns off the display for that coupling. A single missing update does not cause this to occur because there is a chance that transmissions from two transmitters will overlap. Since the ten-second periods are approximate in length and differ for each transmitter, the chance of two consecutive overlaps is much smaller and is much more likely to be caused by loss of radio contact.

Figure 11 is a detailed diagram of the DBI receiver. It shows the decoder for one draft/buff station; the others are identical except for the audio frequencies to which they respond. An FM radio identical to those used in the transmitters receives and demodulates the incoming signal. The filter removes all frequencies outside the narrow band containing the 2N tones. The remaining tone goes to all N decoders and therefore to all 2N phase-locked loops. Each loop is tuned to one of the frequencies of interest.

One decoder accepts the incoming tone if it pertains to the specific coupling. Upon reception of a tone burst, the two phase-locked loops accept or reject the frequency. Acceptance by one loop indicates draft; acceptance by the other, buff. (Acceptance by both is impossible.) Rejection by both indicates that the signal came from another transmitter and will be accepted by another decoder. If the loops accept the frequency, the flip-flop sets or resets according to the draft/buff condition. Acceptance also triggers the monostable, enabling the display for 20 seconds (2 update periods). The outputs of the flip-flop and of the monostable then enable the appropriate gate to drive one of the two display lights corresponding to draft or buff. The light will stay on until (1) a signal corresponding to the opposite state is received, reversing the flip-flop state and turning on another light, or (2) no signal is received for two time periods, in which case the monostable resets and both lights are turned off to indicate loss of radio contact.

2.3.4 Carrier Frequencies

TSC has used a carrier fequency of 162.675 MHz for its tests and experiments; this is one of the frequencies assigned by the FCC to Federal agencies. This frequency is close to the railroad communication frequencies and is expected to have similar propagation characteristics. For day-to-day use in a production DBI, a railroad could use its normally assigned communications frequencies. If the DBI audio tones interfere too much with the voice communications, they can be adjusted either in amplitude or in frequency and filtered from the audio channel. This would not involve any significant change in the design of the DBI.

2.3.5 Display

The DBI display consists of pairs of yellow (upper) and blue (lower) lights corresponding to the successive draft/buff sensor/transmitter packages along the train, as shown schematically in Figure 2. The upper light of a pair represents buff; the lower, draft. The colors were chosen to avoid confusion with red and green status indicators in the locomotive cab. The display incorporates a lamp test and a brightness control.

2.4 MODIFICATIONS AND UPGRADING TO DBI

After initial field testing, TSC installed the DBI on a number of regular revenue freight trains. This experience led to the addition of features but no change to the basic concept.

2.4.1 Acceleration Measurement

The DBI, as described in Section 2.1 - 2.3 above (called the "ten-light DBI"), shows the user where and how often selected couplings change draft/buff states. It does not directly indicate whether these changes are accompanied by smooth motions or violent and damaging shocks. As an option, therefore, a linear accelerometer built into the transmitter package (Section 2.4.3 below) detects the relative amplitudes of car body shocks. The display on this system has an added row of light-emitting diode (LED) characters above the draft/buff light pairs; these characters show the shocks on a relative scale of 0 to 7. The calibration of this scale depends on the expected maximum force.

Because radio-telemetry of shock-level information as well as of draft/buff data involves more data than the audio-tone method could accommodate, the "accelerometer DBI" transmitter converts its information to digital form. A modulator-demodulator (modem) then encodes it into frequency shift key (FSK) mode for transmission. FSK mode is more practical than use of the large number of discrete frequencies the audio-tone method would require. FSK mode is more sensitive to interference, so higher-quality radio sets are required than for audio-based communications. To reduce interstation interference this system as implemented uses carrier monitoring at each transmitter to hold transmissions until the band is free. This eliminates overlapping transmissions and simplifies the task of checking radio contact, at a cost of slight transmission delays.

2.4.2 Data Recording

Both the ten-light and accelerometer DBIs encode their data for transmission as analog signals in the audio-frequency range. The information may be recorded on a standard audio tape recorder prior to decoding. (See Figure 1.) The recorder inserted at this point can store the tones in their proper temporal relationship; an inexpensive portable cassette recorder can provide satisfactory results. The tapes can then be played back in the laboratory through the DBI decoder to obtain a record of the original DBI data for analysis on a paper chart recorder, an electronic counter, or a computer. Section 3.2 below contains examples of train analysis using such recordings.

2.4.3 Packaging

The small high-quality radio transceivers used in the DBI transmitter and receiver allow the units to be quite compact. Figure 12 shows the typical mounting of the transmitter. The sensor is the small box clamped to the platform just above the draft gear in the center of the picture. The cable to sense the inter-car distance is barely visible, stretched between the cars. A retractable cord connects the sensor to the transmitter clamped to the car end ladder. The hi$_k$· transmission frequency allows the use of the short flexible antenna. The carrying case holds all five transmitters and sensors in a set (Figure 12); it also contains a recharger for the batteries in the transmitter. Both the transmitter and the sensor clamp to any available part of the car body, using set screws to tighten the clamps. Mounting the transmitter as shown, on the outside of the ladder, keeps it from posing a safety hazard. The only danger in mounting the sensor results from the requirement of briefly working between cars; the user must determine that the train will not be moved while anyone is working between the cars.

Figure 13 shows the DBI receiver package in use in a locomotive cab. The display (top center) has a rheostat to adjust illumination level. It is equipped with a cable and a magnetic fastener so it can be placed wherever the user finds it most convenient. The receiver package (lower left) can be placed on the floor where it does not obstruct movement. If radio reception is inadequate using the built-in flexible antenna, one can attach an antenna with a cable to the socket and place the antenna on the exterior of the locomotive. In areas where reception is difficult, TSC has used a short whip antenna with a magnetic base attached to the roof of the cab.

Figure 14 shows a close-up view of all the controls on the DBI receiver. In this picture the display is attached directly to the receiver; the cable is not in use. The display is for the accelerometer DBI; the ten-light version would not have the row of digits on top. On this model, the blue lights (indicating draft) are located below the yellow lights (buff). This receiver includes the following features:

- Two seats of rechargeable batteries.
- Built-in battery recharger, from 110 VAC power.
- Variable display intensity.
- Connection for power from external battery.
- Tape recorder connections for input (previously recorded tape drives the display) or output (to record on tape).

Decoded draft/buff analog output for each channel.
Bulb test to allow the user to determine if the lack of signal on a station is due to bulb failure or to a temporary radio frequency signal loss.

3. FIELD TESTS AND EVALUATION

Four prototype DBI Systems were fabricated, bench tested and supplied to selected railroads on a no-cost loan agreement. The terms of the agreement stipulated that the railroads could use the systems in the manner they found most valuable and that they would provide periodic reports of the applications and performance of the Systems. Systems were loaned to the B.N., the Chessie System, Conrail and the SPTC. The following sections describe and give examples of the analysis techniques used by the railroads, their applications of the DBI, and the conclusion reached with regard to the application of the systems.

3.1 ANALYSIS OF DBI DATA

As mentioned in Section 2.4.2 above, the DBI information can be recorded, as it occurs, for later study. Consider the following hypothesis: The engineer should strive (1) to minimize the number of times a coupler state changes, thus avoiding an excessive number of run-in and run-out shocks, and (2) to keep each coupler in either draft or buff most of the time. (Obviously these two goals are effectively the same, but one may be easier to illustrate.) The following describes a graphic method of illustrating and testing the hypothesis.

Figure 15 is a sample of the raw DBI data. On this test, station number 5 was closest to the caboose and number 1 closest to the head end of the train. The train was ascending a steep grade with helpers at the rear. During the portion of the run represented here, the head end of the train seems to have been mostly in draft and the rear mostly in buff, with less stable conditions in the middle portion of the train. The number of transitions from one state to another can simply be counted, while the time spent in each state by a station can be measured and percentages calculated.

Figures 16-19 show the number of DBI transitions for various trains and conditions; the graphs are superimposed for each train on schematic representations of the train makeup, so that unusual train configurations can be noted and taken into consideration. The location of each DBI station in the train is also shown. Figures 16 and 17 show the same train, first (Figure 16) on curving track, operating without helpers. Figure 16 shows relatively little slack action, as expected under the relatively simple conditions. In Figure 17, there was more slack action, most of it in the front half of the train. The engineer was using his air brakes to control the train in the undulating territory, and the propagation of braking from the head end rearwards, along with the light block of cars near the head end, caused the head end to "bunch up".

Figures 18 and 19 show a different train operating uphill with helpers at the rear. As we might expect, the strong draft forces at the head end and the strong buff forces at the rear prevented significant slack action at the couplers near the ends. In the center of such a train, however, there would be a power node between draft and buff forces. Near this node the coupler forces are small compared to those near the ends of the train, so there is a greater likelihood of "floating" couplers and frequent changes from buff to draft and back. This is obvious in both Figures 18 and 19. The difference between the figures is that in Figure 19 there was significant slack action near the head end of the train. The run represented by Figure 19 was conducted over track which contained a number of sharp curves. It is plausible, therefore, to reason that the curve resistance of the three-axle truck locomotive at the head end of the train was great enough to slow the locomotives and allow the rest of the train to bunch up behind the leading power consist, thus causing a significant number of draft buff transitions.

The graphs in Figures 16-19 are difficult to interpret because they show the actual numbers of transitions. Conversion to percentages or rates would not be possible because each train moves at a different and varying speed over a given length of track. It would therefore be wrong to attempt to define such quantities as "transitions/mile" or "transitions/hour" because the relations of time and distance change as the train's speed changes. This problem has been overcome by a different graphic method suggested by J. Pinkepank and L. Varga of the Burlington Northern Railroad. This method considers that relative percentage of time during a run that each coupling is in draft or buff. This requires more calculation than the graphs of the number of transitions, since one must measure time intervals instead of merely counting transitions. These graphs contain more information than those depicting transition alone as they indicate which states the parts of the train were in. Figures 20 and 21 show the percentage of time in draft and buff corresponding to Figures 16 and 17 respectively. In these sections the train was mostly in draft; but in Figure 21, the increased slack action at the head end of the train is again noticeable. It would seem that one of the two curves is redundant, since the two states are both mutally exclusive and exhaustive, but the two curves do make the graph easier to interpret, as the following example shows.

Figures 22 and 23 correspond to Figures 18 and 19, for the train going uphill with helpers. The point where the two curves cross on each graph is the approximate location of the power node of the train, where the drawbar force is zero, dividing the front part being pulled from the rear being pushed. Figure 23 clearly shows the effect of curves on the train, as the curve resistance of the locomotives caused the front and rear of the train to bunch up.

It is anticipated that further data collection and analysis will extend the possible uses of the DBI for train-handling analysis. For example, in a train with a power node, as in Figures 22 and 23, it is not possible to have each coupling near the node in draft or buff 100% of the time. The following hypothesis may be considered: The steeper the slopes of the draft/buff curves near the node, the more stable the train. Figures 24 and 25 illustrate this hypothesis. In Figure 24 the train was going uphill between mileposts 1631 and 1628, on the Burlington Northern Railroad. Here, one of the helpers failed and so the power node shifted rearward, as would be anticipated. A second change can also be noted: the slopes of the lines representing draft and buff on Figure 24 are less steep than those in Figure 25, which is the continuation of this test with the helper now operating properly. In Figure 24 at the fourth station, there was buff about 60 percent of the time and draft about 40 percent of the time. This means that there was a great deal of motion (some of it possibly severe) at that coupling. In Figure 25 at the fourth station, there were buff 100 percent of the time and much less motion. With the use of the accelerometer-type DBI sensor, it should be possible to investigate such hypothesis further and perhaps to develop quantitative indications of proper train handling.

3.2 APPLICATIONS AND USE

The DBI has been used successfully for two related purposes, the development of improved handling procedure in order to optimize the economical use of rolling stock and the analysis of train operations which have had stability problems resulting in derailment damage to track structures and rolling stock.

The following example of the first sort of use was reported by Mr. Edward Lind of the SPTC: In order to optimize the operation of long freight trains on mountainous terrain, radio-controlled helper units may be distributed within the train. Each helper is intended to provide traction and braking power to the train segment surrounding it. Segments are separated by power nodes or locations within the train, where the influences of the locomotives before and behind a string or group of cars are balanced. It is highly desirable to maintain the power node at a stable position within a group of cars, as shifts in the node's position can be accompanied by violent car motions. It is also important to insure that for any given type of operation the node does not occur at the helper itself, as this would indicate that the power unit is contributing little if anything to the train movement and may even be hindering operation. The SPTC used the DBI to develop procedures for radio-controlled helper operation. It did this by placing DBI sensor stations at couplings surrounding the helper units and monitoring the position and occurrence of the nodes. A road foreman (training officer and first-level supervisor) rode in the cab of the helper and used the information provided by the DBI display as "real-time" feedback in the evaluation of various handling procedures and strategies designed to improve radio-controlled helper operation. Use of the system resulted in profound changes in operating instructions to the engineer. For instance, it was "conventional wisdom" that the throttle of the trailing radio-control units should be advanced or lead the leading power units by at least one position or notch to insure train stability. Information provided by the DBI indicated that this generalization is often false and that in a number of situations train operation can be enhanced when the throttle of the trailing units is on a lower notch or power setting than that of the lead units. While the above example was provided by the SPTC, the system has also been used successfully by the BN and Chessie System for this purpose. Detailed examples of analysis of train stability and node position are provided below.

The DBI has also been used for the optimization of non-helper operations. The following example was provided by Mr. Willis Copeland of Conrail. The normal procedure for descent of a particular long grade is to operate in a "stretch-braking" mode (the air brakes are applied but the locomotive provides sufficient tractive effort to keep the train stretched.) This is done to keep the rear of the train from "running in" as the front makes the transition from the downgrade to level track. After it is estimated that the run-in danger is past, the brakes are released. The particular point of release is critical as late release is uneconomical and early release could allow run-ins and damage or derailment. In the particular incident reported by Conrail, it was observed that the last (rearmost) DBI station showed a buff condition immediately after the brake release was made at the customary point. The operating personnel noted this and prepared modifications of the instructions on brake release for engineers. Before these changes could be communicated, a second train passed over the same area and a derailment occurred at the rear of the train. In this case the information provided by the DBI provided both the basis for an improvement in operating procedures and a plausible explanation for a derailment.

As noted above, the DBI has been used in the analysis of accident causation. Two examples of this sort of use were provided by the SPTC. In the first, the railroad experienced a series of unexplained derailments on mainline track and it was hypothesized that they could have occurred due to undetected slack action. Analysis of data gathered with the DBI did not reveal significant action; this indicated that the explanation was unlikely. With slack action eliminated from consideration SPTC personnel sought alternative explanations for the derailments. They eventually found that violent truck hunting on refrigerator cars and automobile carrier cars, produced by the particular track conditions, was the most likely cause of the derailments.

In the second example derailments of ore trains moving from a mine to the main line were investigated, and data gathered with the DBI indicated that slack action was a major problem. Based on the analysis of the DBI data a number of new operating procedures were devised, evaluated, and adopted. Among the procedures adopted were the following:

1) A series of five loaded 85-ton ore cars must be placed immediately behind the lead power units in each train.
2) All dynamic brake applications must be preceded by a minimum service air application to "set up" the train.
3) Changes in speed of the trains are to be held to a minimum in order to reduce slack run-ins and run-outs. To accomplish this, uniform and very conservative speed limits have been put into effect on the territory under study. The low limits are not set with regard to maximum safe operating speed (they are well below this level in many areas) but in order to minimize the requirement for changes in speed.

4. CONCLUSIONS AND SUMMARY

This report discusses the development of a data collection and recording system to support the development and evaluation of improved train-handling procedures. The DBI as described is a fully developed prototype railroad instrument system with a wide variety of applications in train handling, train analysis, and engineer training. The device has been used successfully for a number of purposes: the development of new operating procedures, the investigation of derailments, the determination of the role of train-handling procedures in accidents, and the analysis of the effects of various train makeups, helper placements, and operating procedures in the operation of long trains. Finally, study of the data from the DBI has indicated that it can potentially be used to discriminate between engineers of varying skill levels.

Information provided by railroads using the DBI indicates that the use of the system as a real-time train handling aid is premature. Although the DBI was originally conceived and designed to aid the engineer by providing information on slack conditions within the train, its use in this manner is severely limited by the following two problems. First, the sensor-transmitter stations must be mounted after the train has been made up. The time required (approximately thirty minutes) is not available under current yard procedures and installation requires that the installer have access to the entire train; this is often not possible within existing yard configurations. The second problem involves the real-time use of the information displayed by the DBI. Instructional material has not yet been developed and evaluated for integrating the DBI information into revenue-service train-handling procedures.

Nevertheless, the inherent value of displaying train-dynamics data to the engineer in real time is obvious in that it represents a significant step towards providing the engineer with feedback on the results of control inputs. Future developments in control display designs may be expected to increase the quantity and quality of feedback information available to the engineer. In-cab real-time displays of information such as train-force distributions, total power-force levels, potential lateral-to-vertical force-ratio hazards, and the occurrence of truck hunting or car rock and roll integrated with information on slack action can be expected to provide significant support to the engineer's efforts to optimize train handling. Future developmental efforts are necessary to evaluate this hypothesis, but in the interim, researchers and railroad operating personnel can gain valuable insights into the effects of slack action on train handling using the DBI.

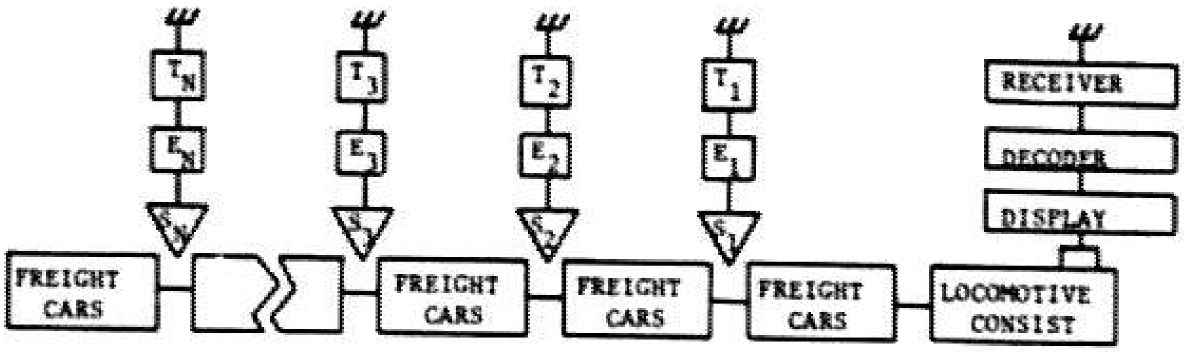


FIGURE 1 SCHEMATIC DBI INSTALLATION

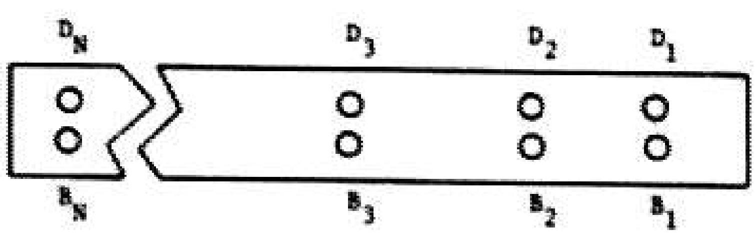


FIGURE 2 SCHEMATIC DBI DISPLAY

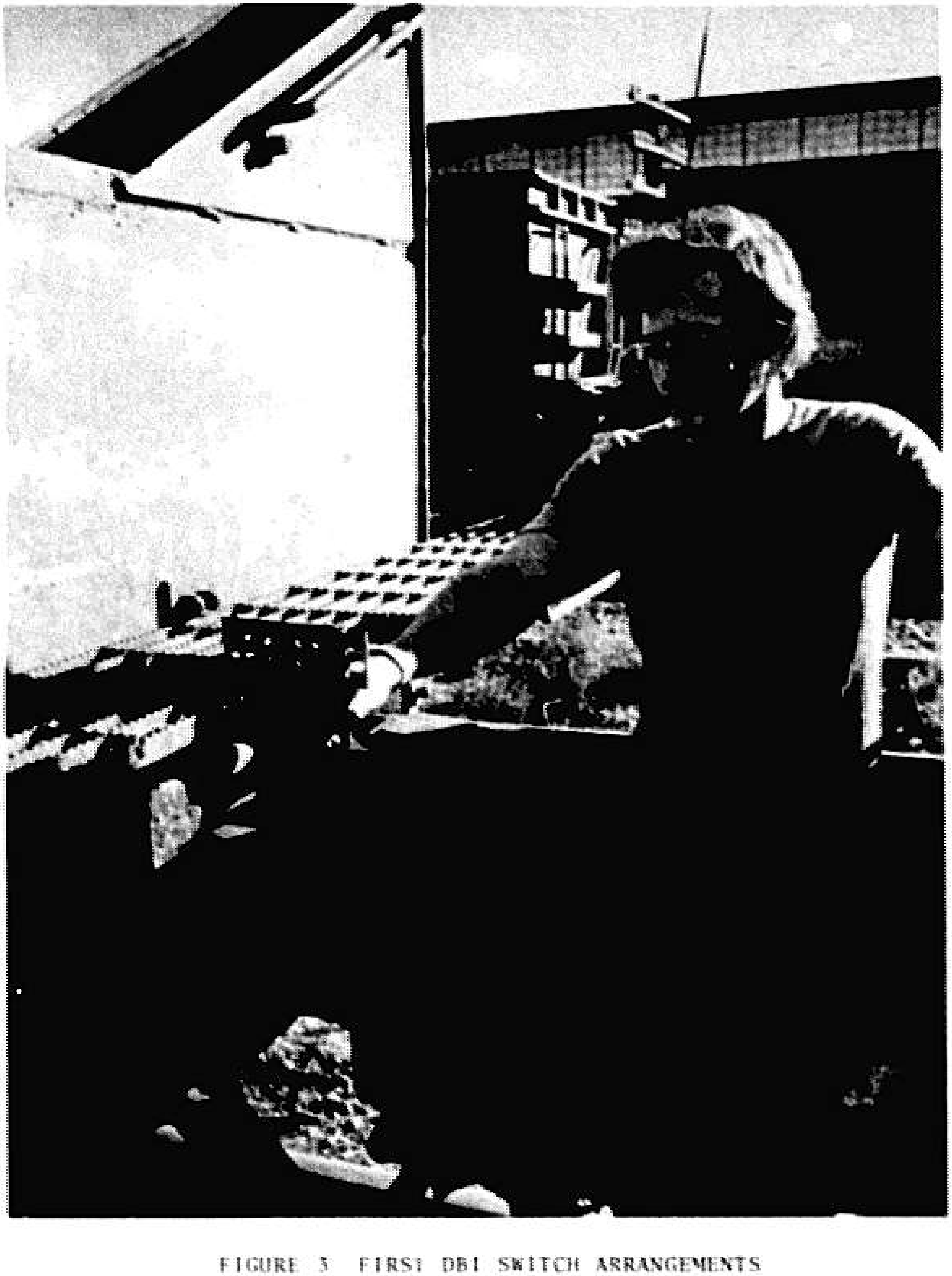


FIGURE 3 FIRST DBI SWITCH ARRANGEMENTS

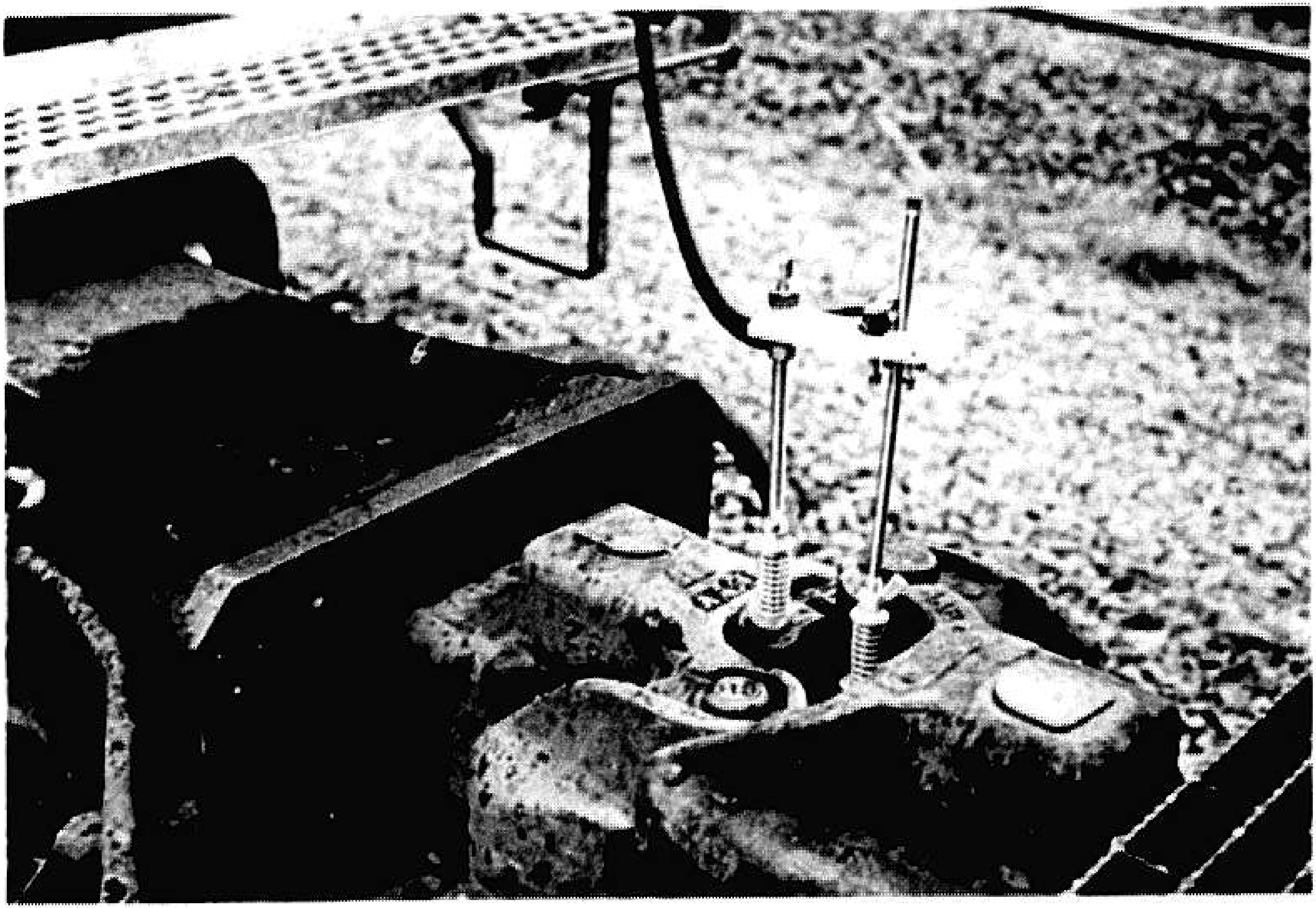


FIGURE 4 DBI CASTING-HOLE DETECTION METHOD

FIGURE 5 TWO-REEL DBI PROTOTYPE

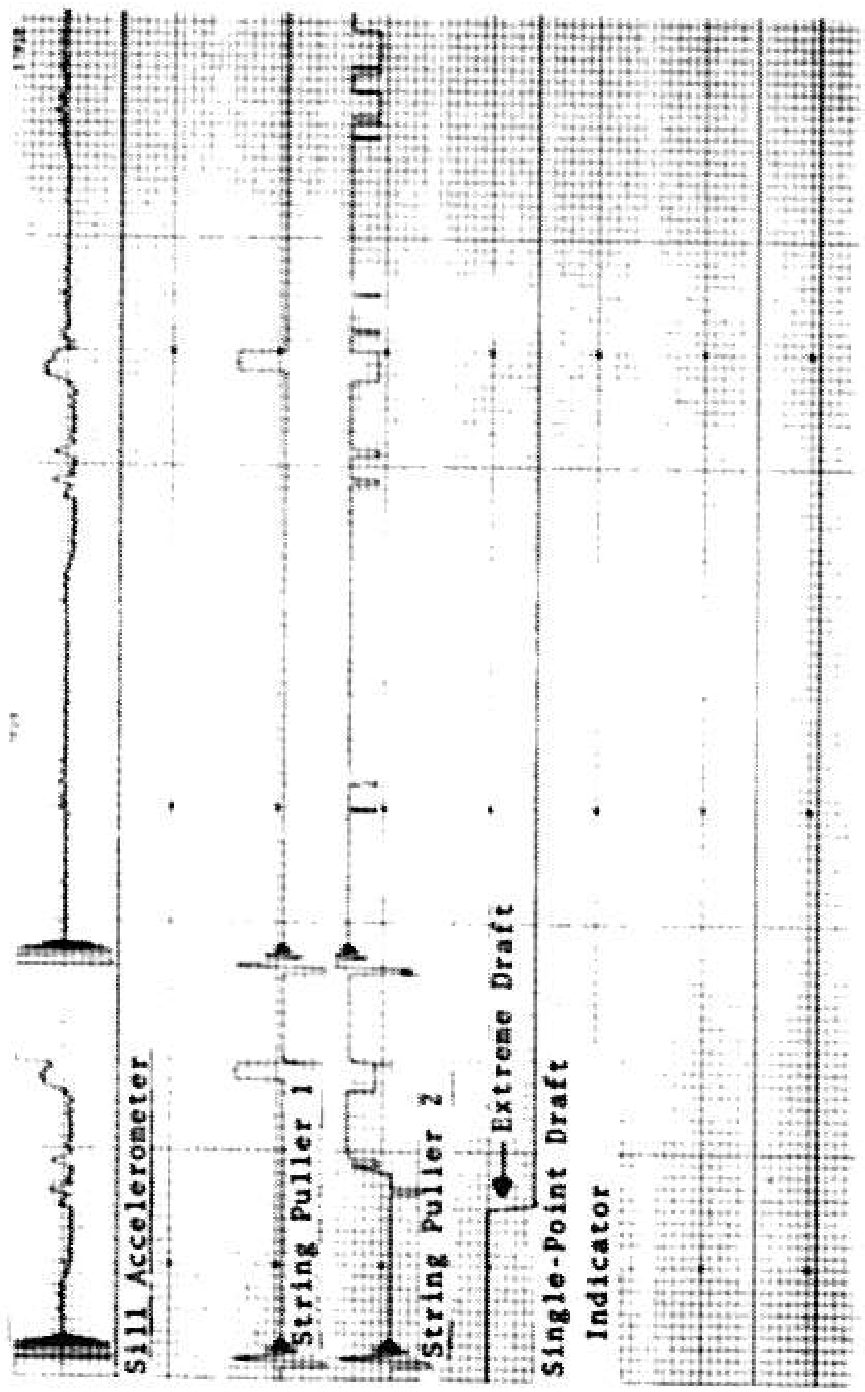


FIGURE 6 DBI RAW DATA: SINGLE DECISION POINT

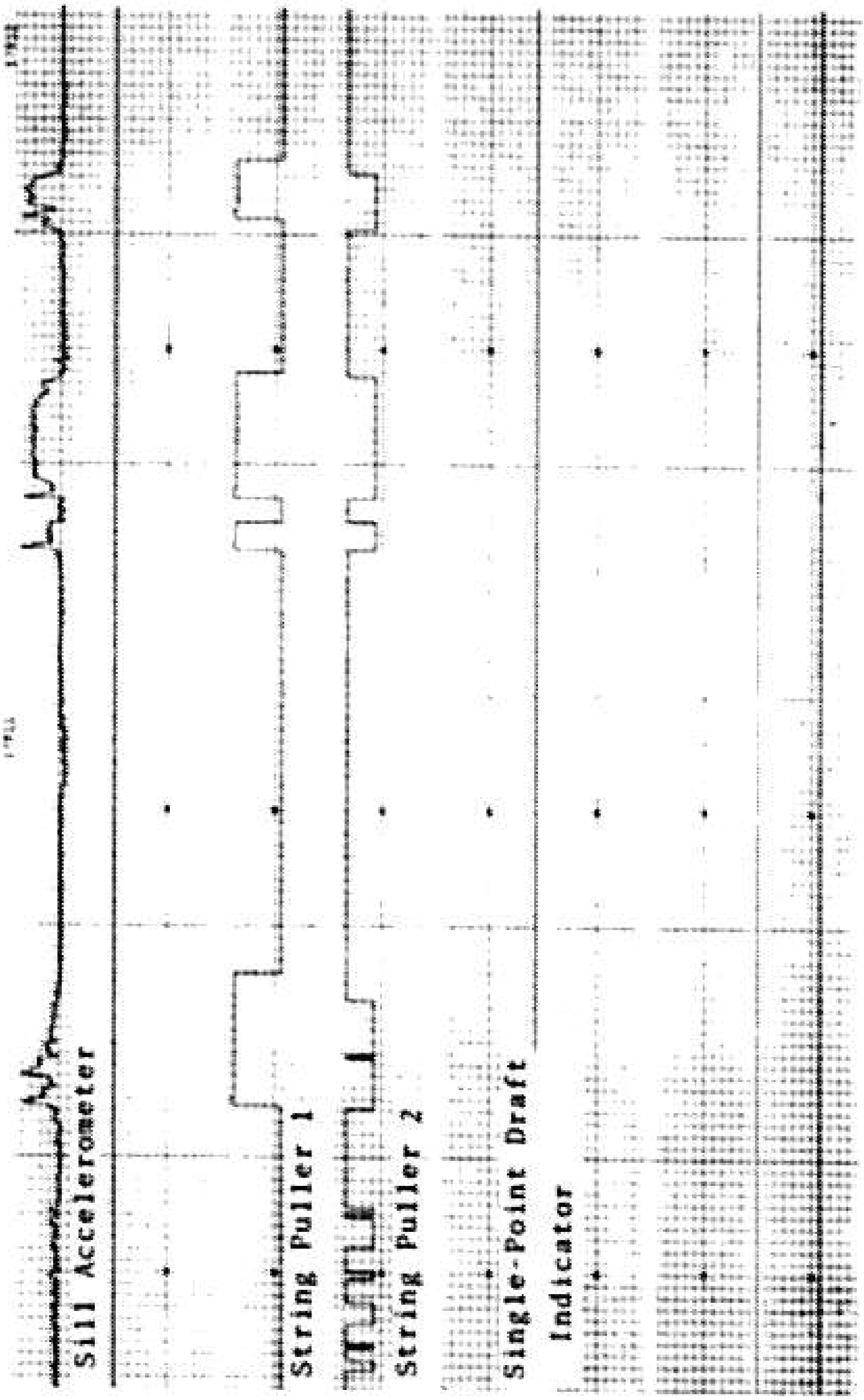


FIGURE 6 CONT'D

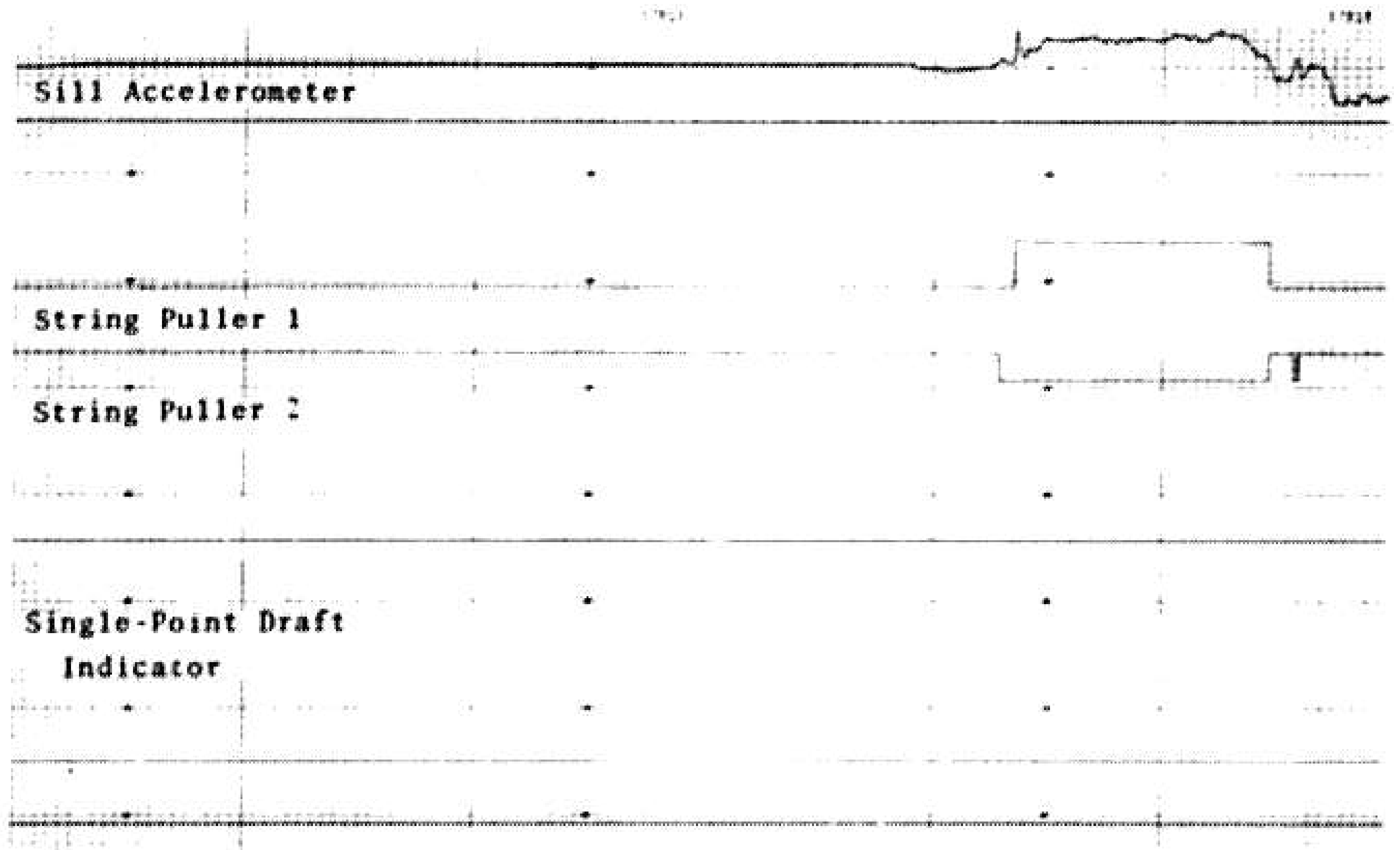


FIGURE 6 CONCL'D

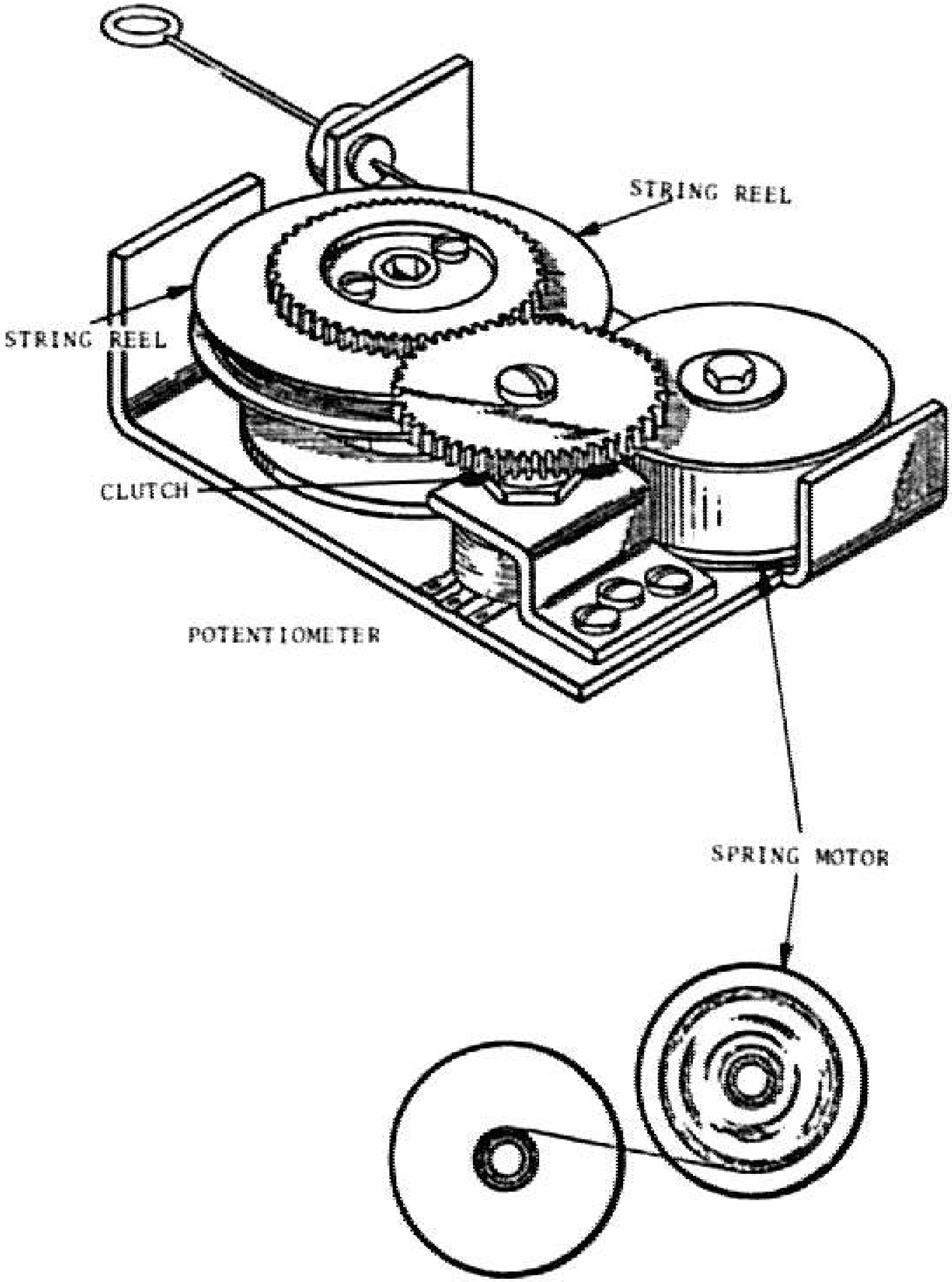


FIGURE ' DBI STRING PULLER WITH HYSTERESIS

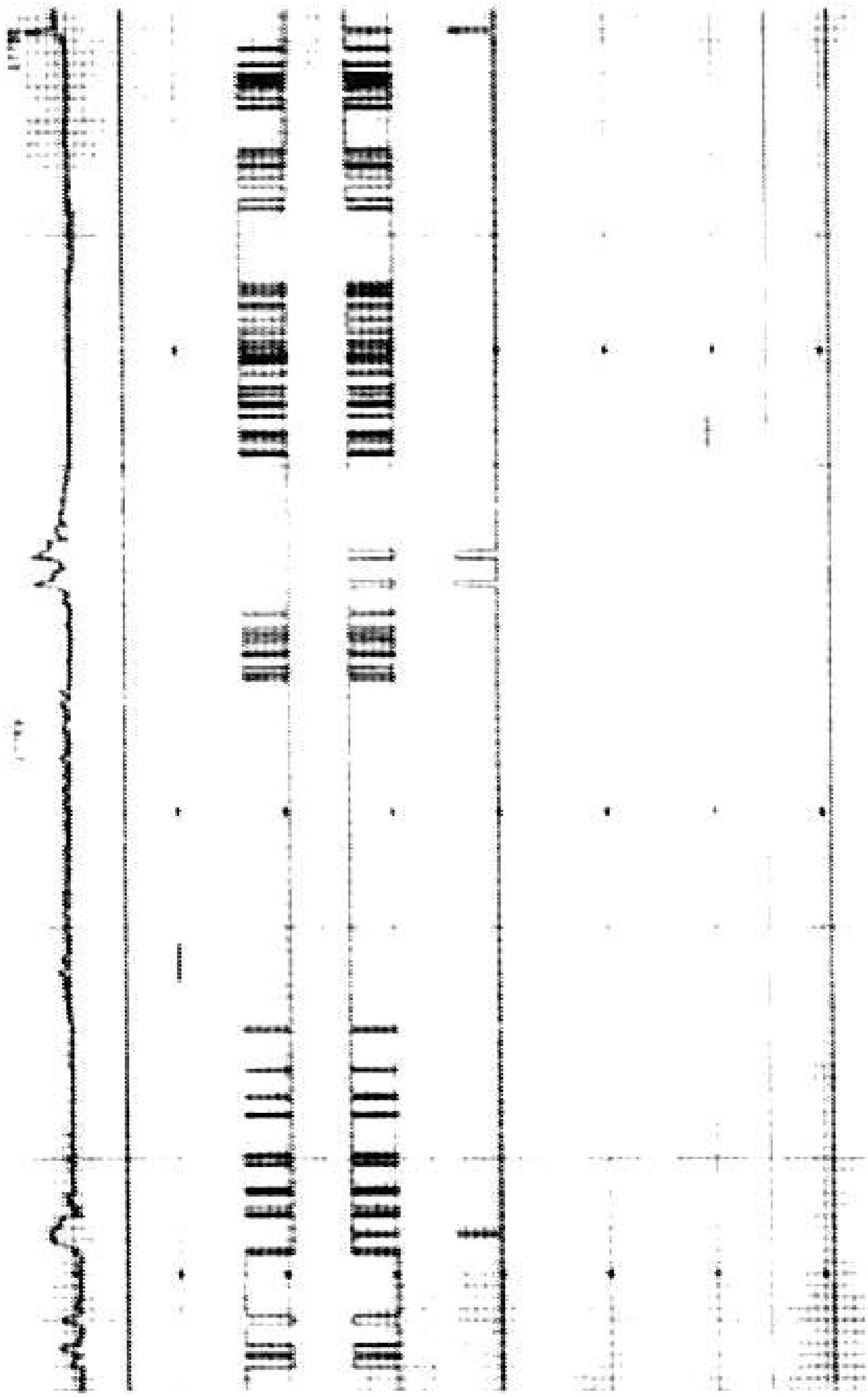


FIGURE 8 DBI RAW DATA: TWO DECISION POINTS
(cf. Figure 6)

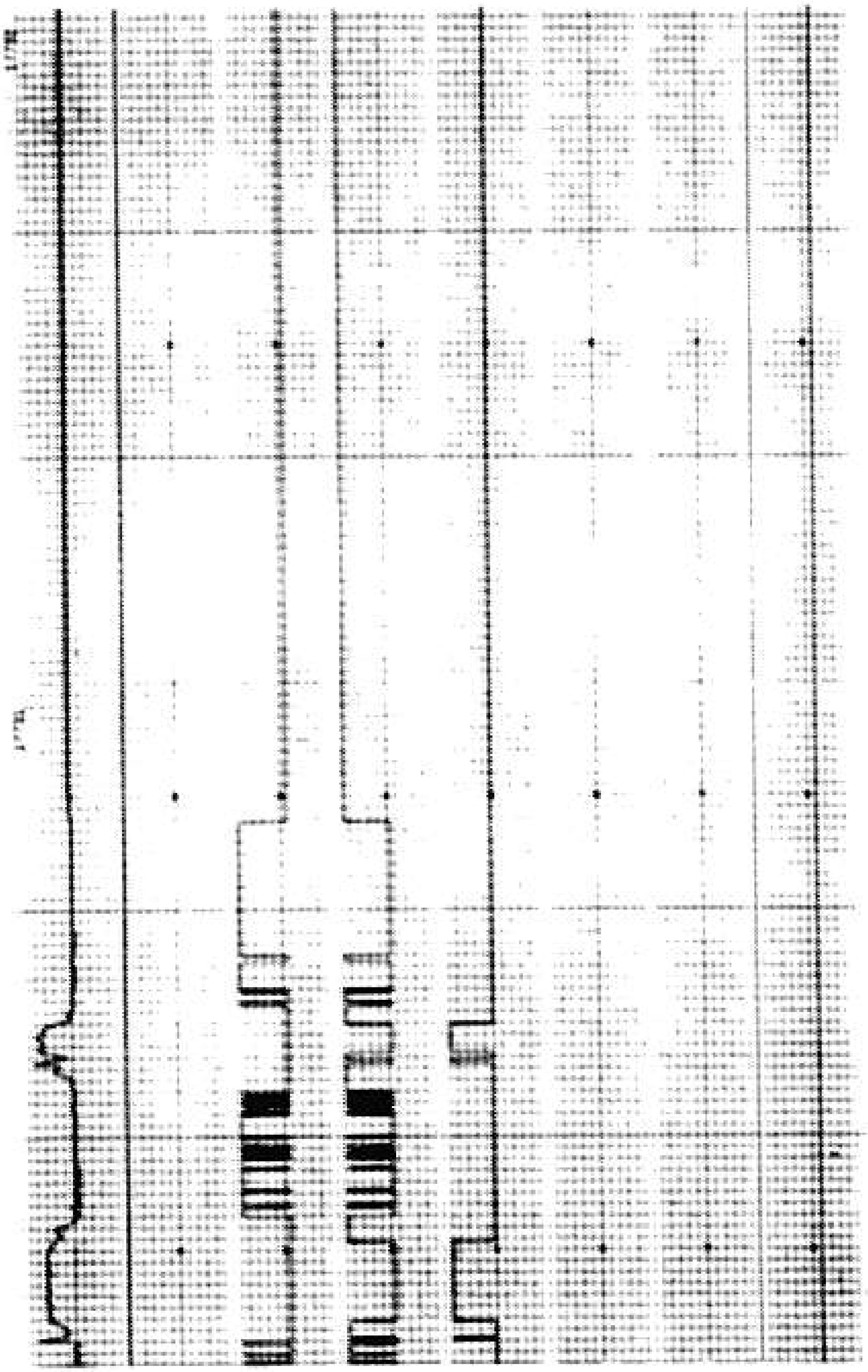


FIGURE 8 CONT'D
(cf. Figure 6)

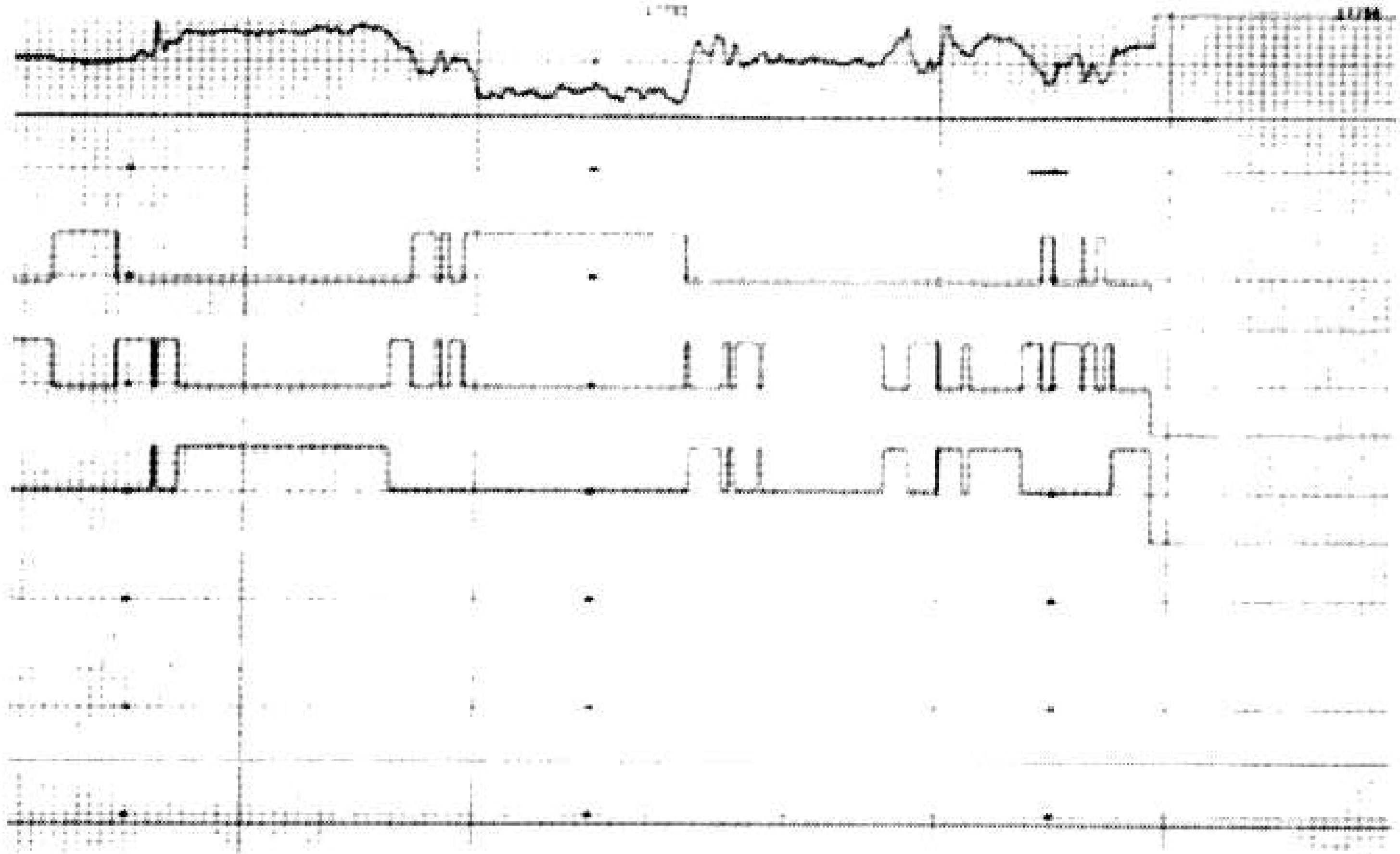


FIGURE 8 CONCL'D
(cf. Figure 6)

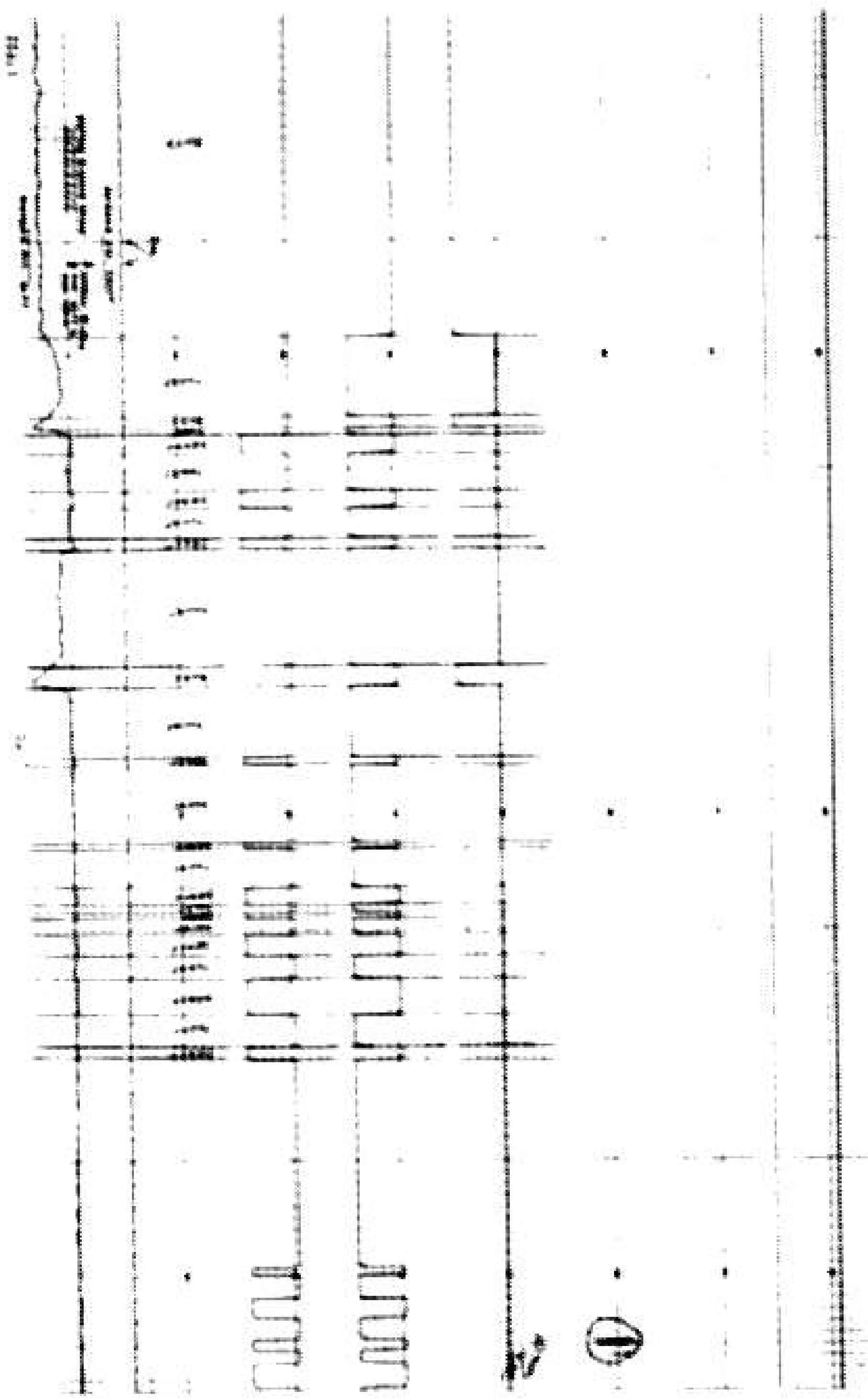


FIGURE 9 EXPANDED SECTION OF TWO DECISION POINTS

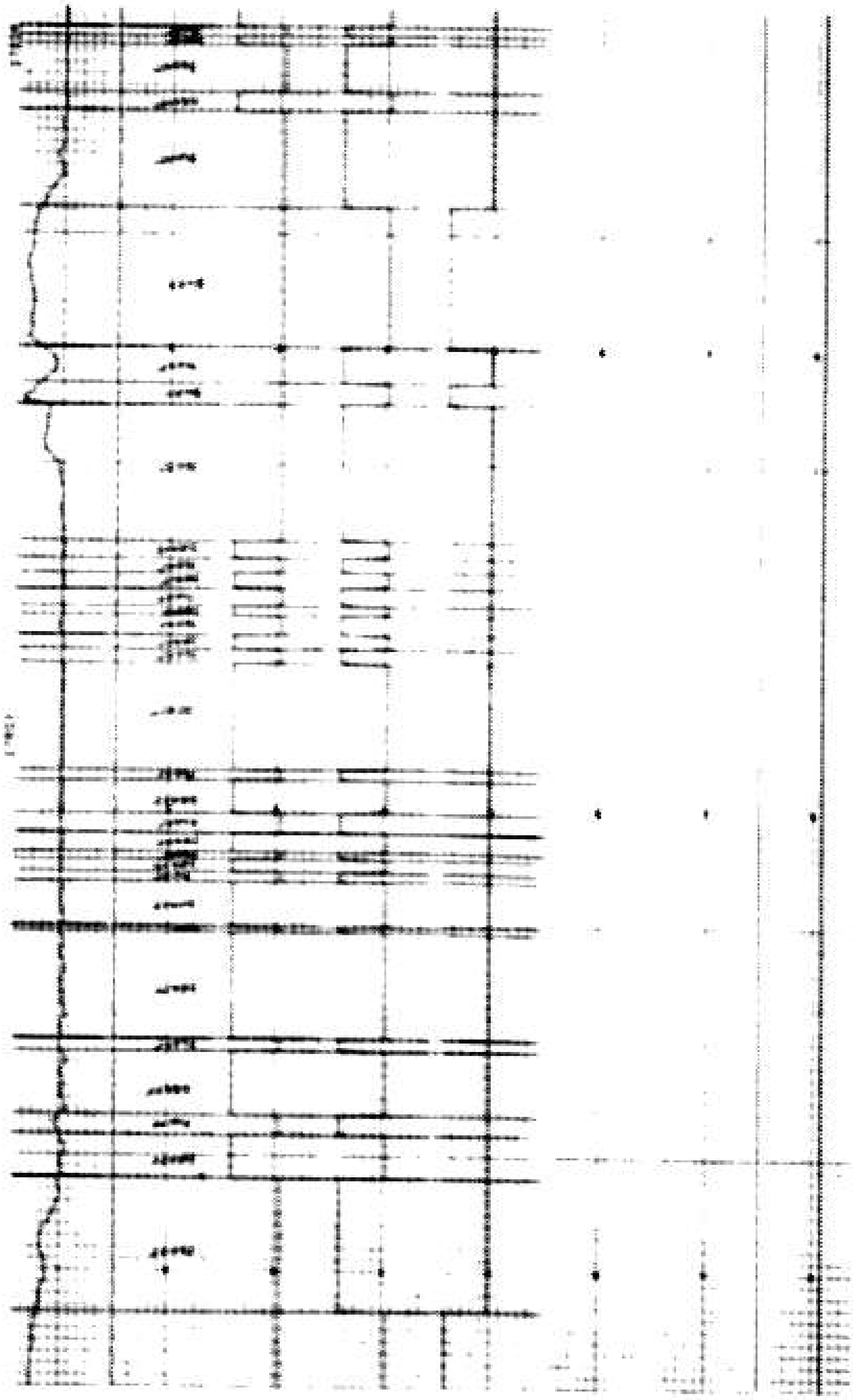


FIGURE 9 CONT'D

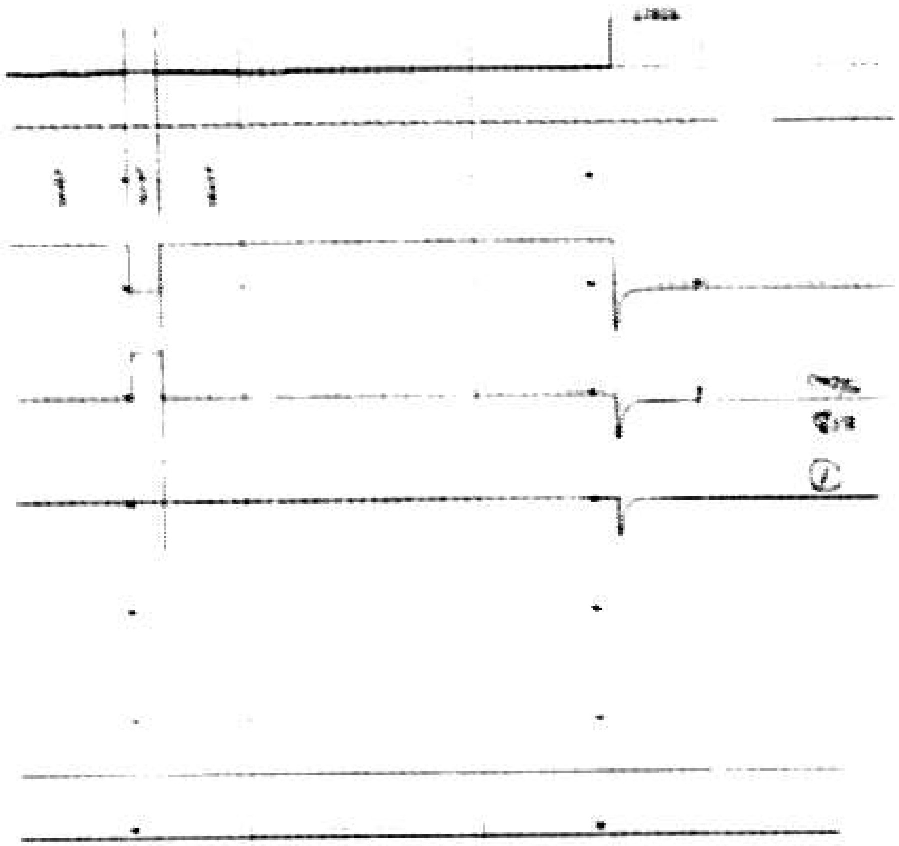


FIGURE 9 CONCL'D

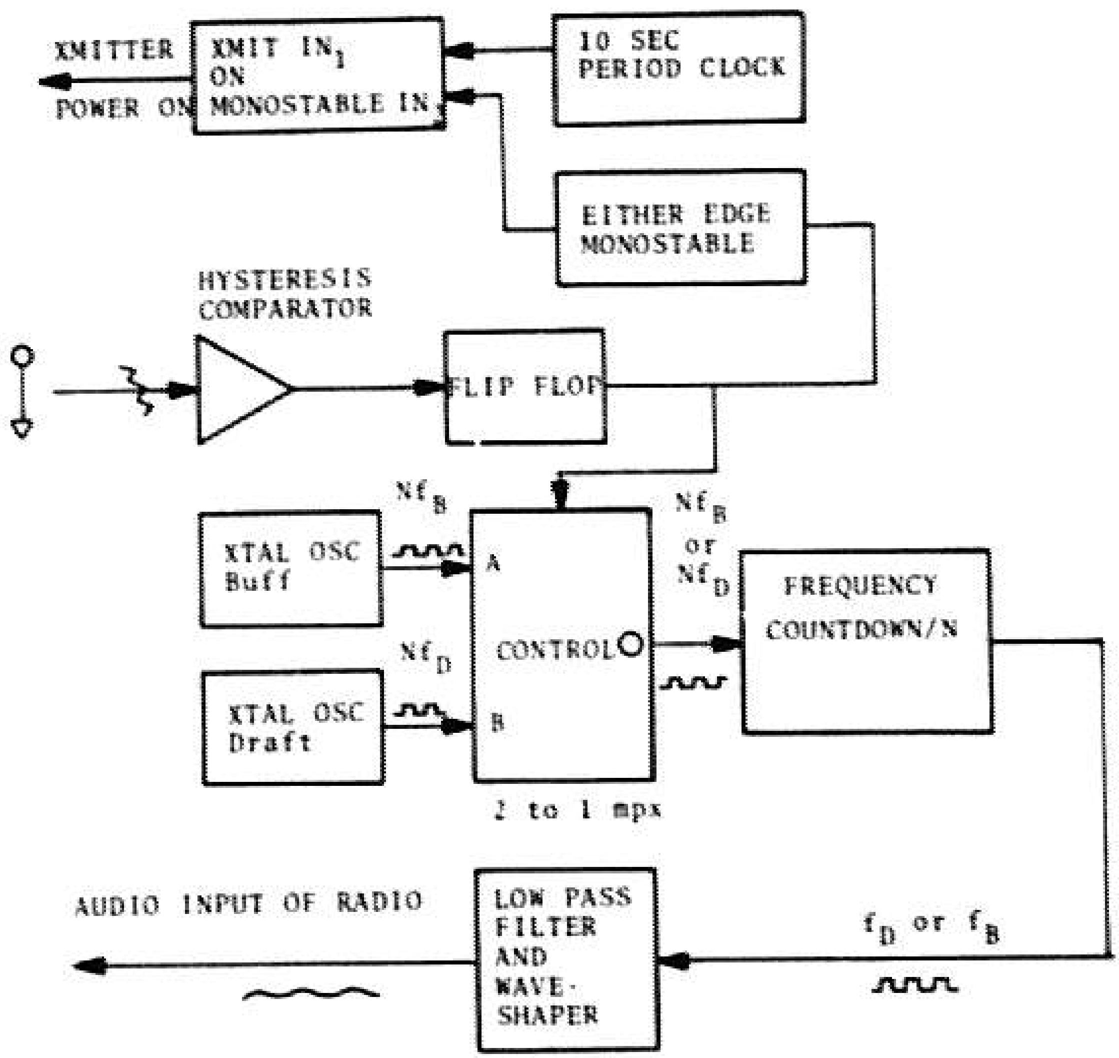


FIGURE 10 DBI TRANSMITTER

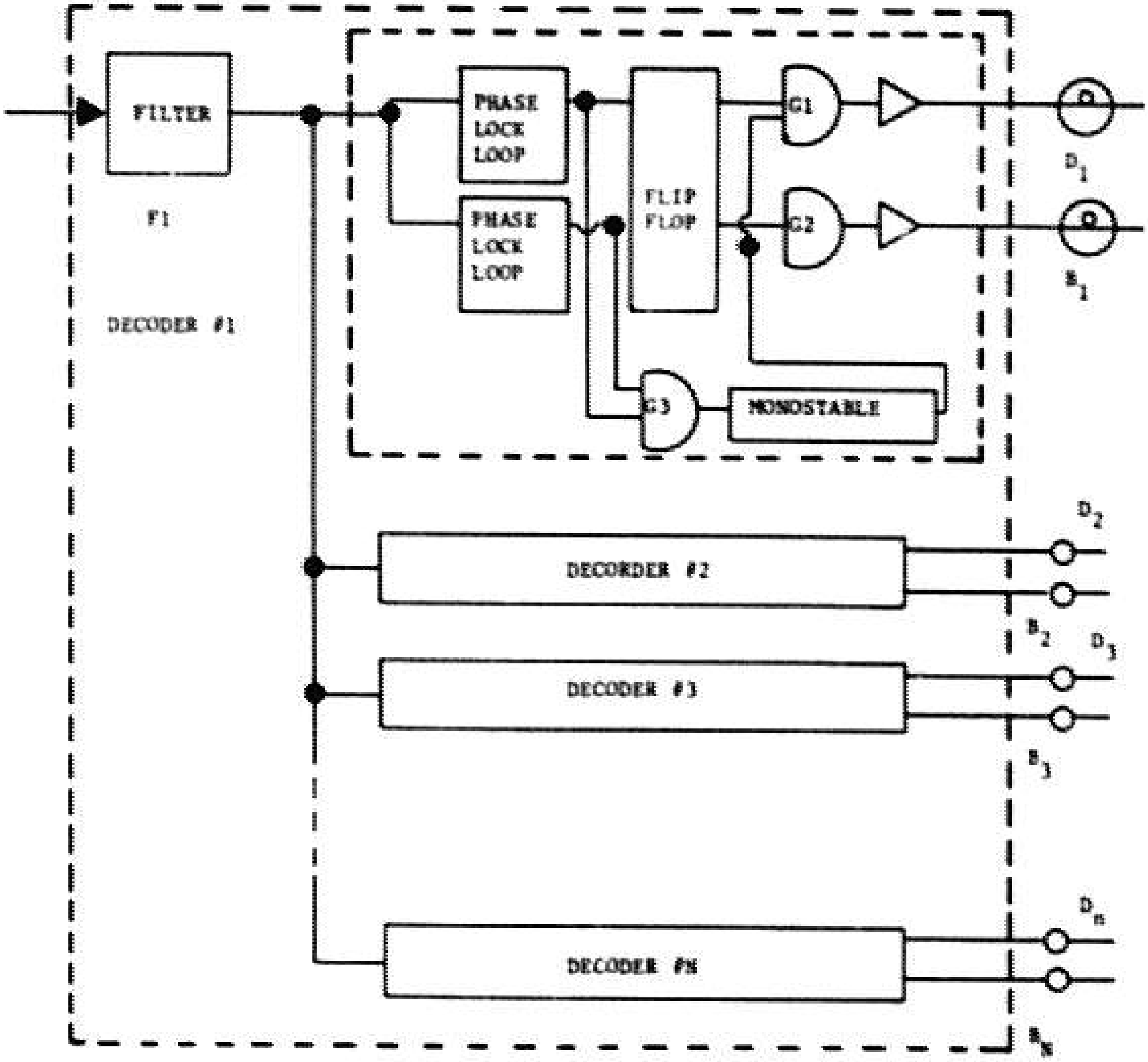


FIGURE 11 DBI RECEIVER

FIGURE 12 DBI TRANSMITTER MOUNTING

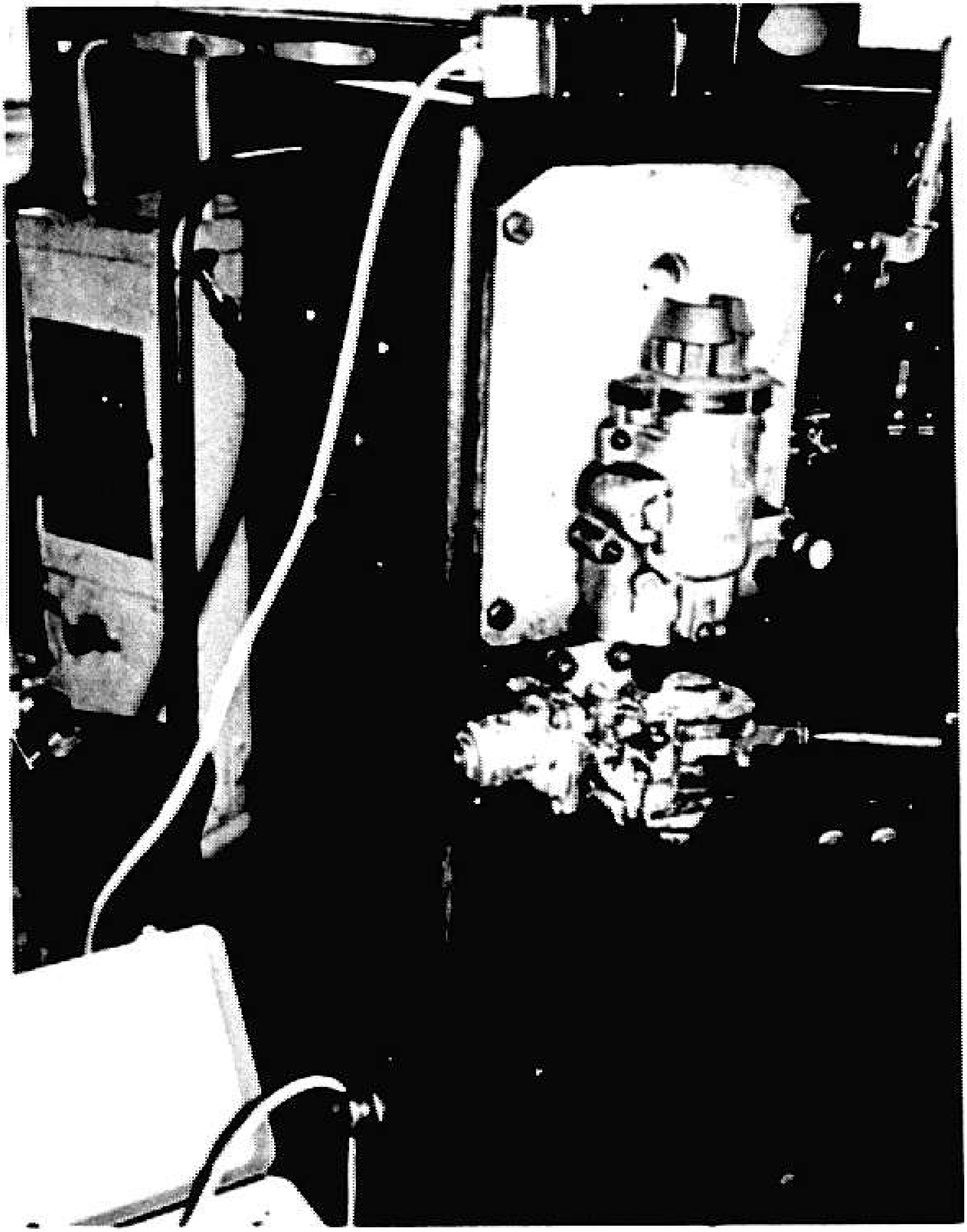


FIGURE 13 DBI RECEIVER MOUNTING

FIGURE 14 DBI RECEIVER PACKAGE

FIGURE 15 SAMPLE OF RAW DBI DATA

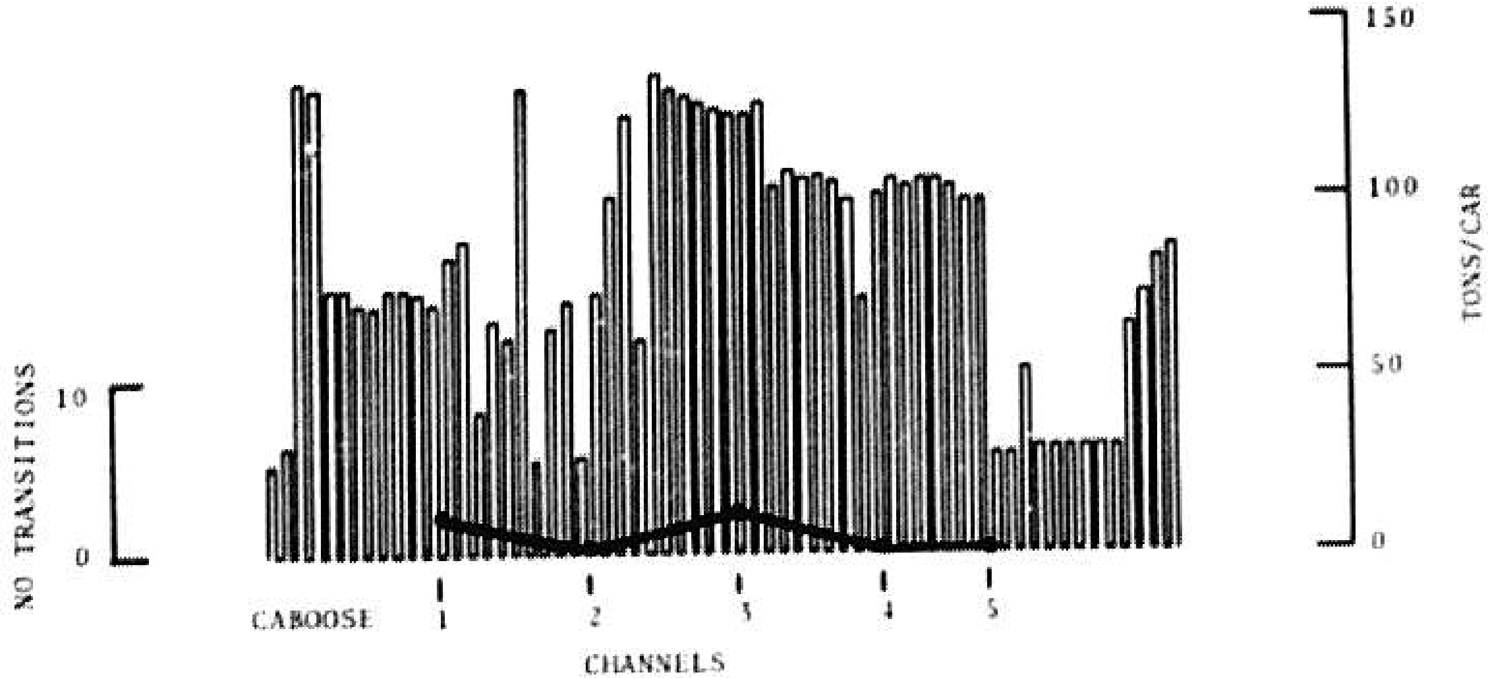


FIGURE 16 DBI TRANSITION GRAPH - SLACK ACTION ON CURVING TRACK

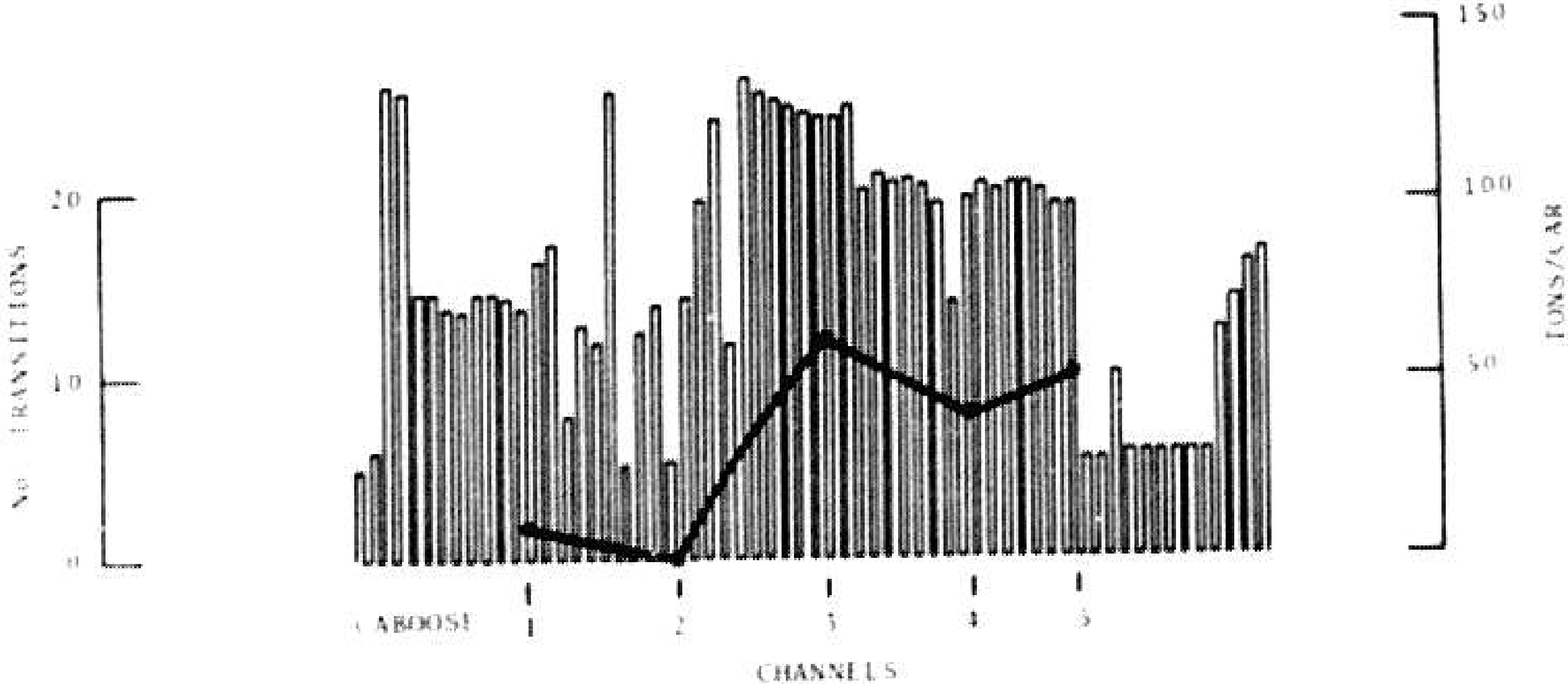


FIGURE 17 DBI TRANSITION GRAPH SLACK ACTION ON UNDULATING TERRITORY

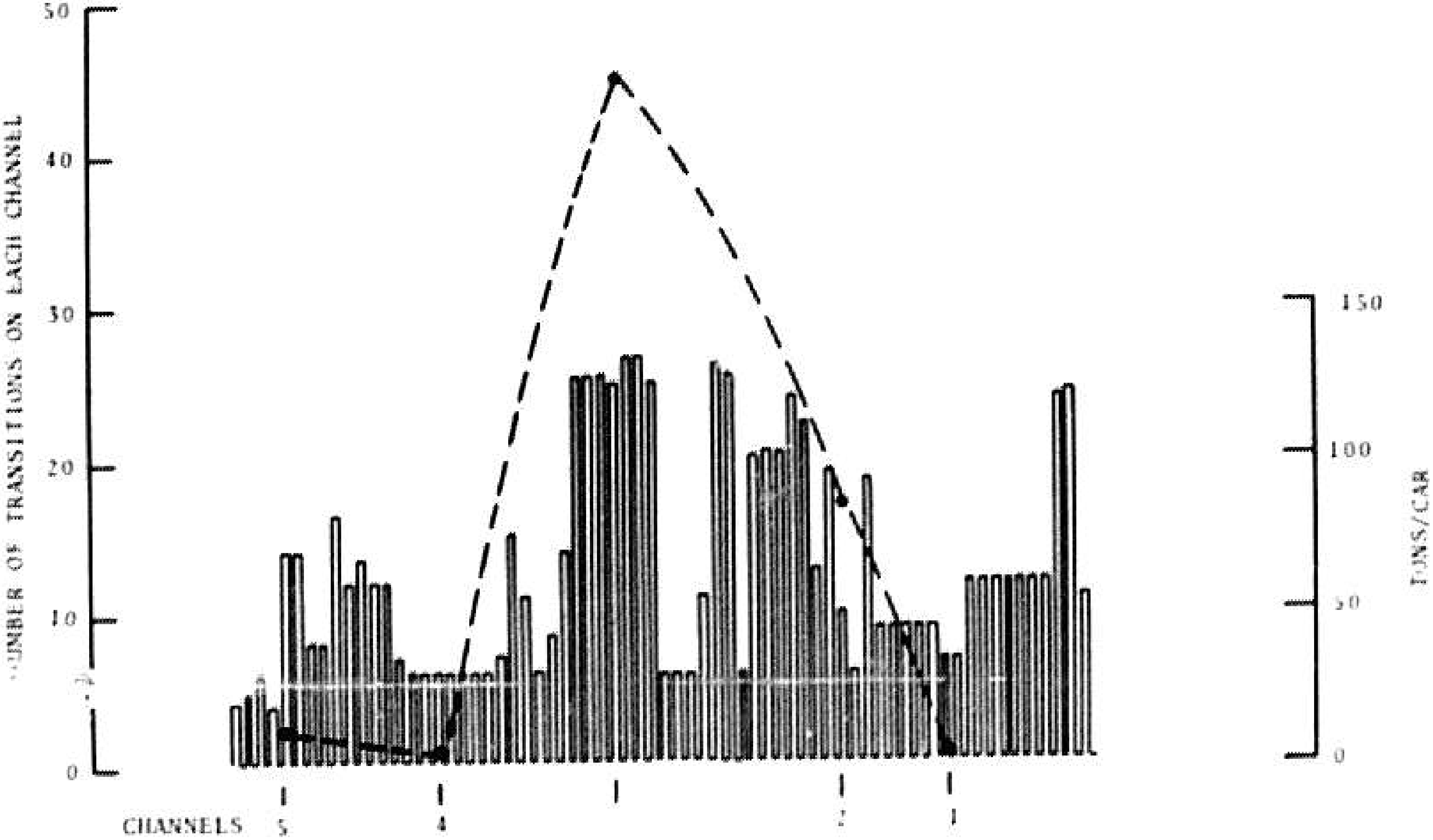


FIGURE 18 DBI TRANSITION GRAPH SLACK ACTION ON ASCENDING GRADE, STRAIGHT TRACK (With Helper Locomotives)

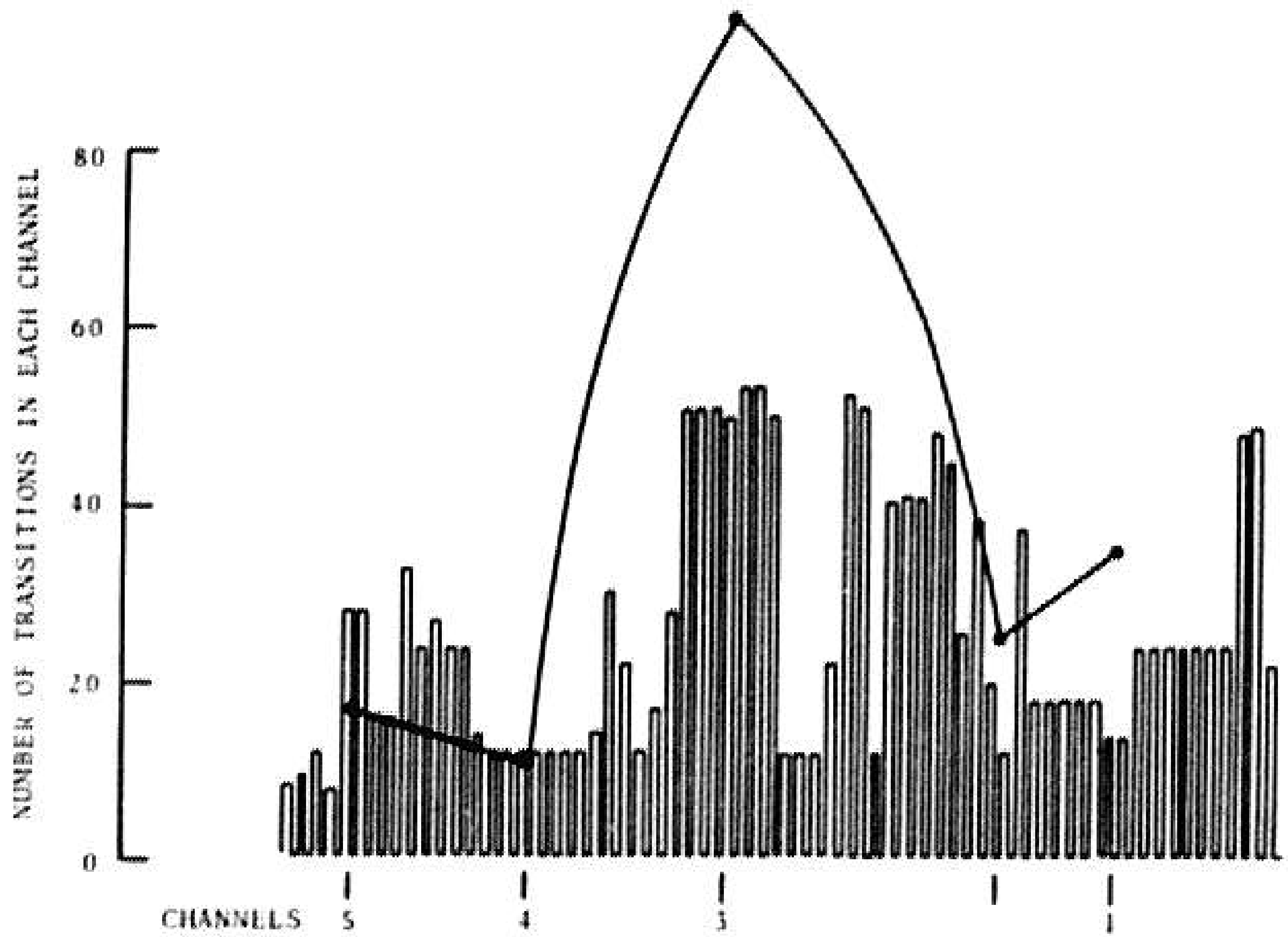


FIGURE 19 DBI TRANSITION GRAPH - SLACK ACTION ON ASCENDING GRADE, CURVED TRACK (With Helper Locomotives)

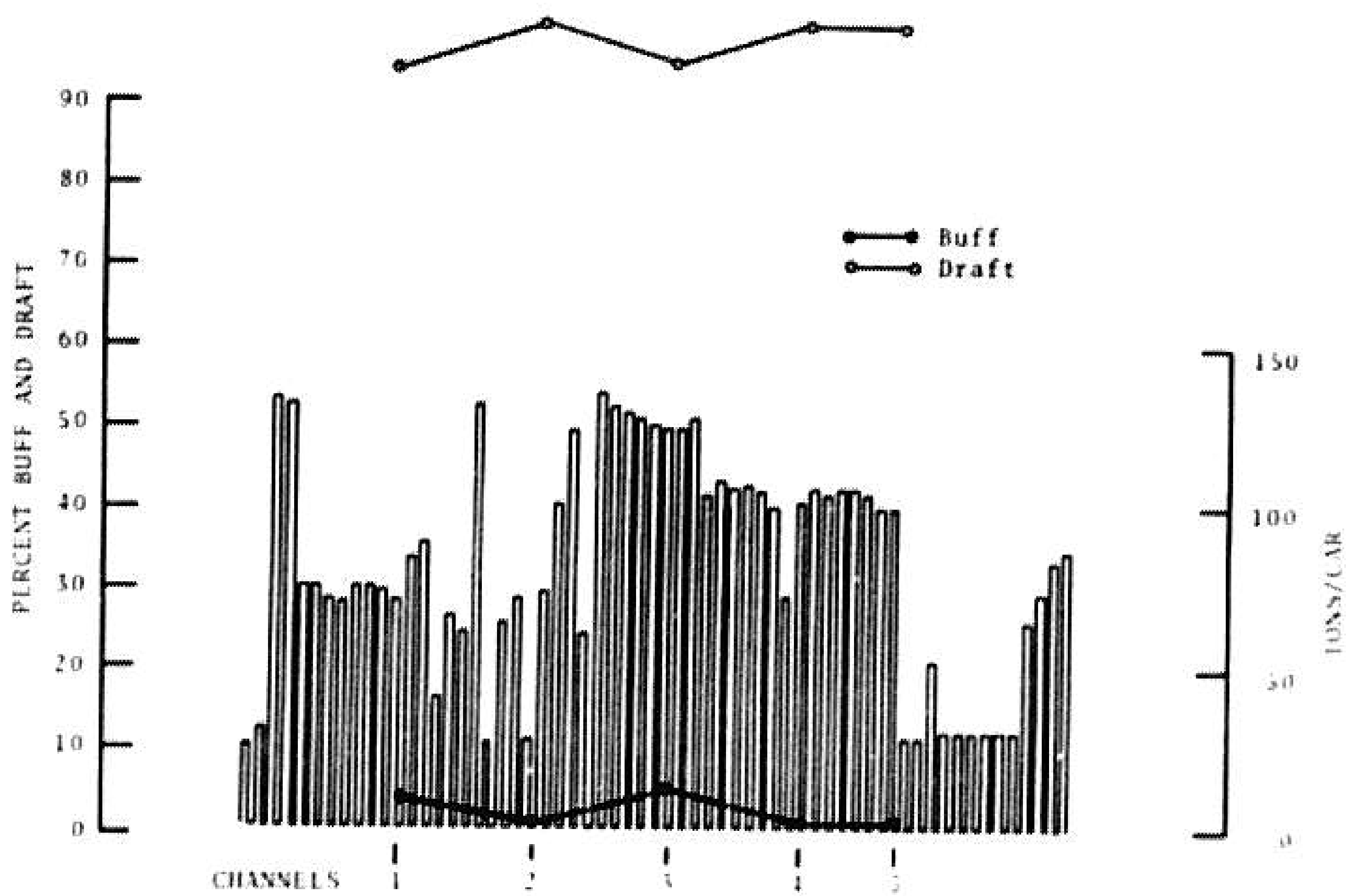


FIGURE 20 DBI TIME-IN-STATE GRAPH – SLACK ACTION ON CURVING TRACK

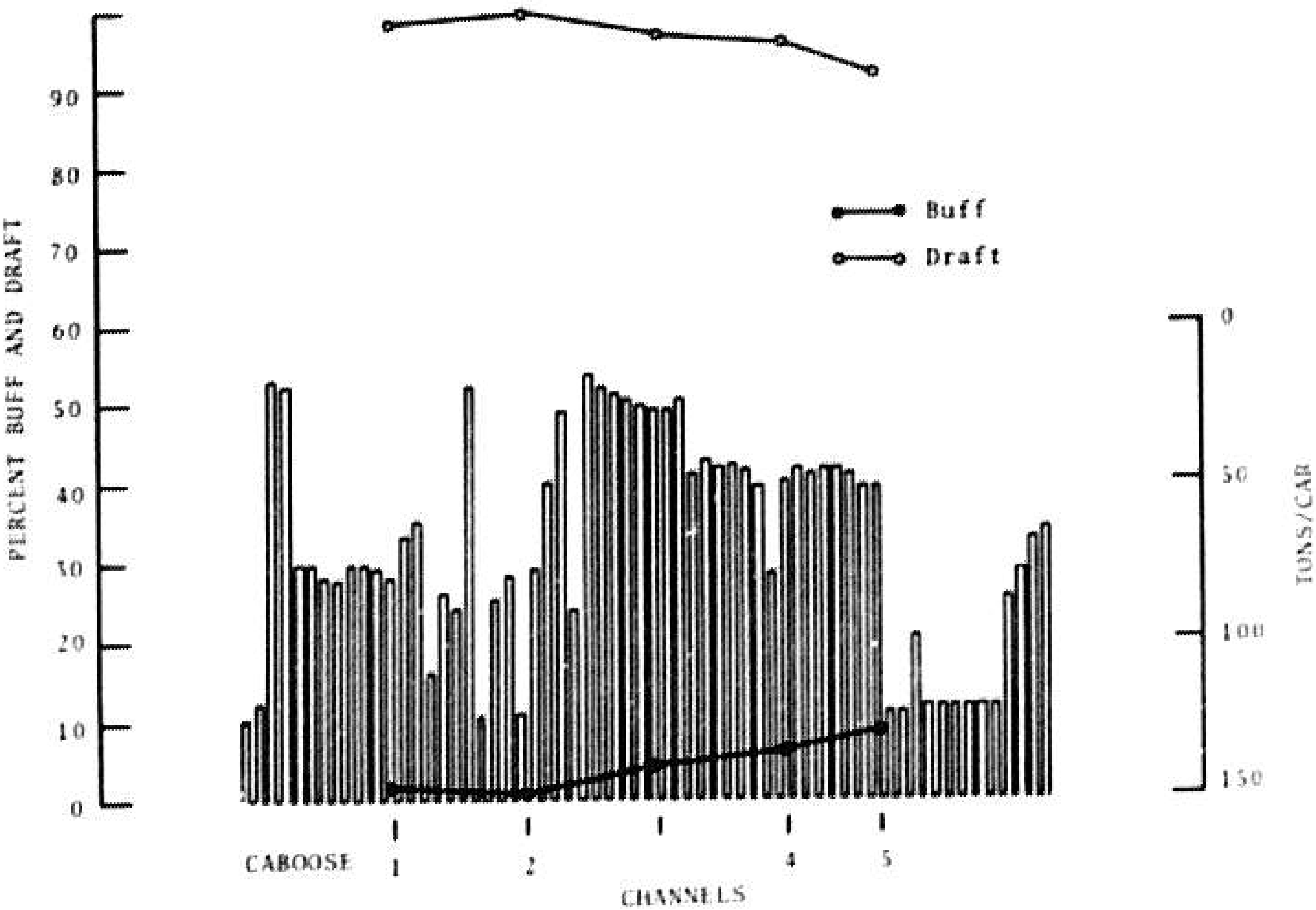


FIGURE 21 DBI TIME-IN-STATE GRAPH - SLACK ACTION ON UNDULATING TERRITORY

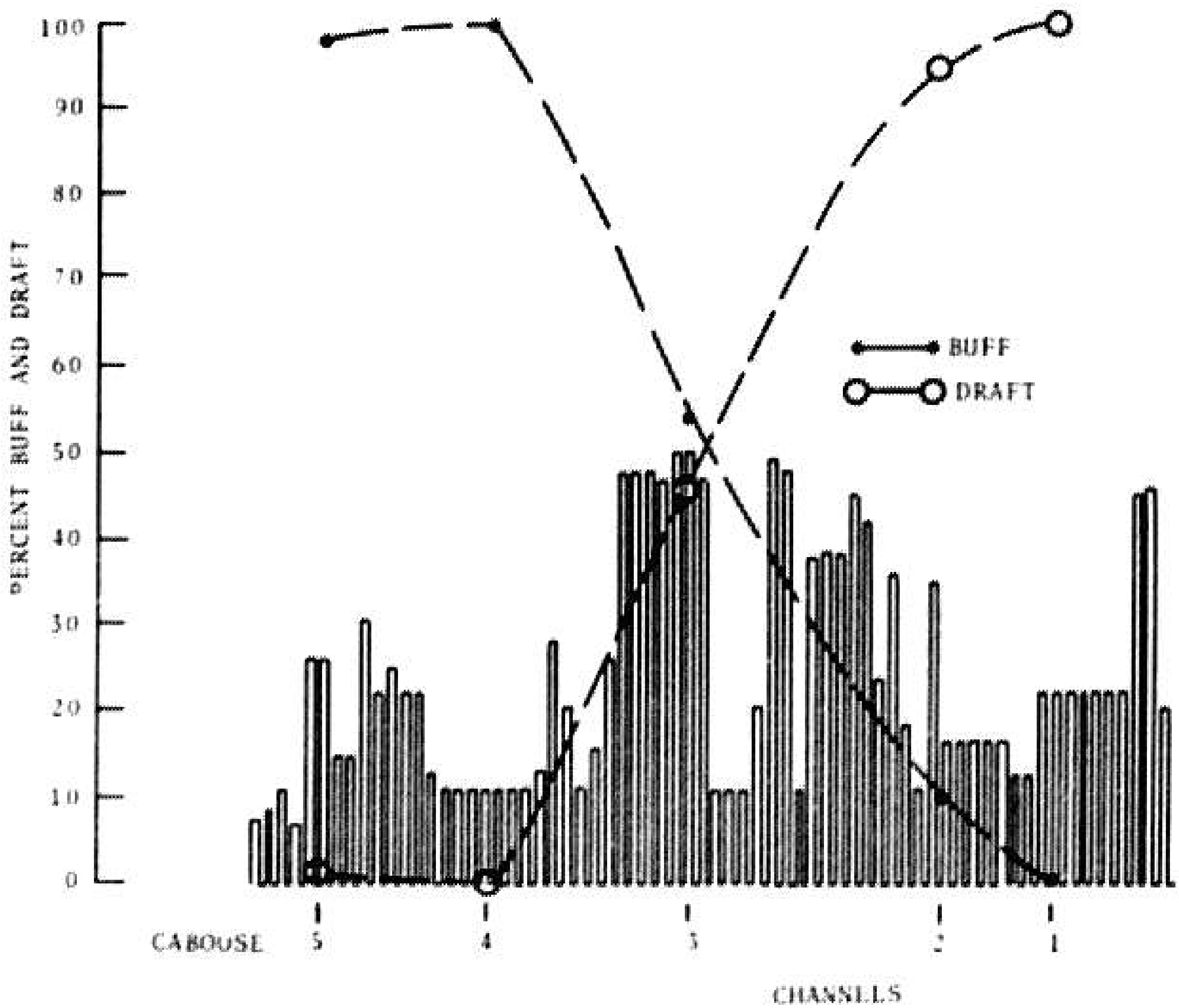


FIGURE 22 DBI TIME-IN-STATE GRAPH - SLACK ACTION ON ASCENDING GRADE, STRAIGHT TRACK (With Helper Locomotives)

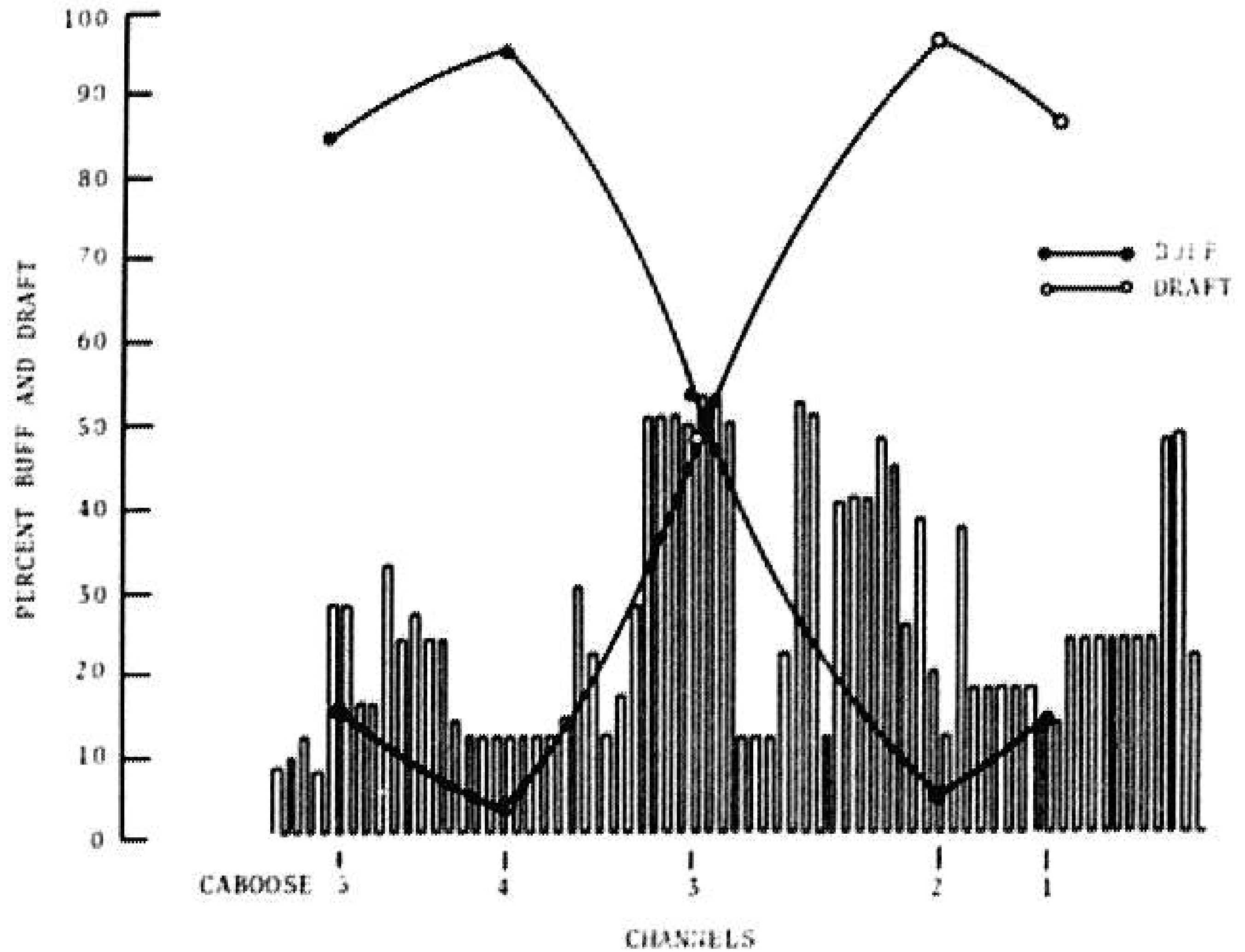


FIGURE 23 DBI TIME-IN-STATE GRAPH - SLACK ACTION ON ASCENDING GRADE, CURVED TRACK (With Helper Locomotives)

MILEPOSTS 1631 to 1628.5

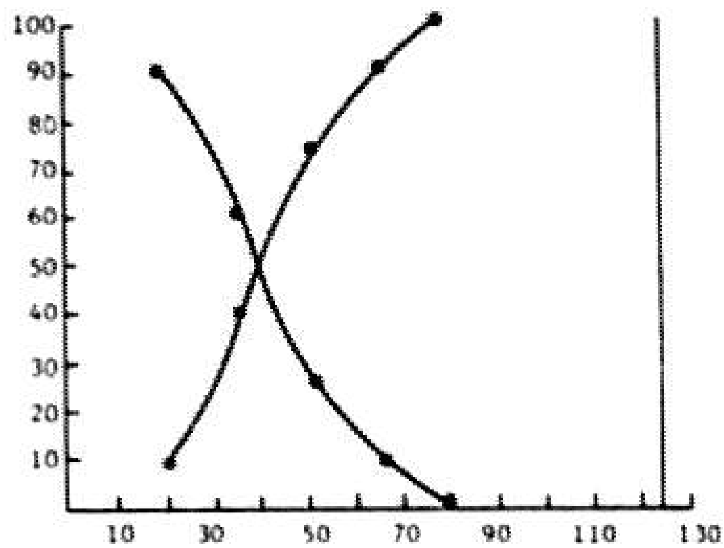


FIGURE 24 DBI TIME-IN-STATE GRAPH - ASCENDING GRADE WITH FAILED HELPERS

MILEPOSTS 1628.5 to 1624

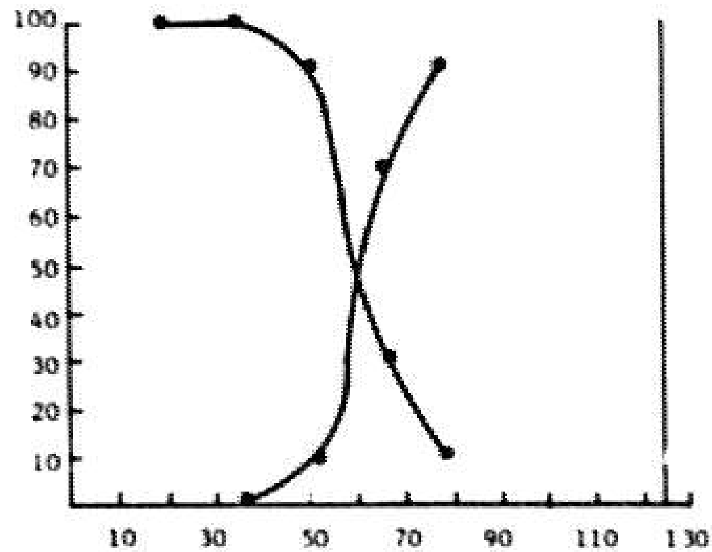


FIGURE 25 DBI TIME-IN-STATE GRAPH - ASCENDING GRADE WITH HELPERS IN SERVICE

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