A mining research contract report
JULY 1985

MINE HOIST ELECTRICAL SYSTEMS STUDY
VOLUME II — DATA/ANALYSIS SYSTEM DESIGN STUDY

Contract No. J0134006
Mining and Engineering Departments, Colorado School of Mines

OFR
87-5

BUREAU OF MINES
UNITED STATES DEPARTMENT OF THE INTERIOR

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CERTIFICATION OF THE ABSENCE OF PATENTS AND INVENTIONS

This statement certifies that at the grant report date, no inventions have been developed from phase II of Contract J013006. Consequently, no patents are pending.

Fred R. Leffler, Project Director

50272-101

REPORT DOCUMENTATION PAGE

1. REPORT NO.

2.

3. Recipient's Accession No.

4. Title and Subtitle
Mine Hoist Electircal Systems Study
Volume II - Data/Analysis System Design Study

5. Report Date
July 1985

6.

7. Author(s)
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8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Mining and Engineering Departments
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Golden, Colorado 80401

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C) j0134006
(G)

12. Sponsoring Organization Name and Address
Assistant Director - Mining
U.S. Bureau of Mines
2401 e Street NW
Washington, D.C. 20241

13. Type of Report & Period Covered
Final Report.
Sept. 1983 - July 1985.

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

Safe operation and system integrity are two important properties of a mine hoist electrical system. Previous methods used to assess these systems, though rare, have involved extensive downtime and required skilled personnel. The recommended design considerations presented in this report are for a proposed automated system that will perform real time measurements, calculations, and recordings of pertinent performance data. Included are equipment installation and test procedures to be used with the system. The report also contains descriptions of the hoist performance criteria, and how they are to be collected.

17. Document Analysis a. Descriptors

Hoist electrical systems
Design consideratons, automated, data, analysis

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement
Release unlimited

19. Security Class (This Report)
Unclassified

20. Security Class (This Page)
Unclassified.

21. No. of Pages
152

22. Price

FOREWORD

This report was prepared bu Colorado School of Mines, Golden, Colorado under USBM Contract number J0134006. The contract was initiated under the Health and Safety Technology Program. It was administered under the technical direction of the Electrical and Electronics Systems Group with Dean Ambrose acting as Technical Project Officer. Janice Johnson was the contract administrator for the Bureau of Mines. This report is a summary of work recently completed as part of this contract during the period September 1983 to July 1985. This report was submitted by the authors in July 1985.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the participation of the following individuals and organizations for their contribution to this investigation. Their contributions regarding technical and regulatory matters was freely given and sincerely appreciated.

R. L. Jones, Electrical Superintendant. Henderson Mine, Empire Colo.

Elmer Shields, Mine Plant Engineer. Homestake Mining Co., Lead, South Dakota.

MSHA Technical Support groups, Pittsburgh and Denver.

Bob Hedlund, Schwartzwalder, Mine Manager, Cotter Corp., Golden Colo.

Dan Henderson, General Electric Field Service Engineering.

Gregory L. Hurd, Product Marketing Specialist, Test Management Systems, Honeywell Inc., Littleton Colo.

Dave Sanders, Test Instrument Division, Honeywell Inc., Englewood Colo.

In addition to the above, the following Mining Companies provided valuable information:

Climax Molybdenum Co.
ASARCO
Texasgulf, Wyoming Potash Operation
Tenneco
Allied Chemical Co.
Bethlehem Mines
U. S. Steel Mining Co.
Peabody Coal Co.
Kitt Energy Co.

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1. INTRODUCTION.

Reliability and safety are the two properties of a mine hoist system which assure accident-free operation. Accidents occur when either or both of these attributes are partially or totally absent. Careful design, installation, testing, and maintenance are the ingredients of a safe and reliable hoist. The presence of a large variety of different mine hoists and therefore hoist electrical systems, makes the standardization of inspection and testing procedures difficult. Because of this wide variety of hoists and the limitations of human knowledge and experience, mine hoist inspections are constrained. Furthermore, hardware and procedures for testing and analyzing data from inspections is rare.

It is common to encounter in the same proximity, systems ranging in complexity from home-made to modern sophisticated automatic hoists. In order to complete a detailed inspection of all the individual electrical components in operation on a hoist, a detailed investigation of the electrical diagrams would be required. In addition, extensive hoist downtime and highly trained personnel would be required to complete such an inspection. Therefore, it is important to ensure that this inspection procedure be as simple as possible, while at the same time offering a reasonable assessment of safe hoist operation. This can be achieved through the inspection of performance attributes of the hoist, rather than individual components.

Safety of hoisting systems is determined by MSHA through mine inspections and accident investigations. Various tests are performed, data acquired and analyzed, and conclusions drawn. An assessment is then made on the safety of the hoist system. The time between the end of the tests and drawing conclusions can be lengthy, due to the amount and form of the data, largely repetitive calculations involved, and analyses required.

A system that will reduce the assessment time involved by using an automated method for gathering the parameters from hoist and controls testing, performing calculations, and doing an analysis to determine the operational status of the hoist, has been proposed. This system will be able to collect data while the hoist is operating and limit the amount of hoist downtime required during a mine hoist electrical system inspection.

The investigation of all the parameters that could be measured in a mine hoist electrical system would be a formidable task. This investigation yielded those parameters which could be measured within the constraints of a practical automated inspection system, i.e., a limited amount of hoist downtime, availability of instruments, knowledge of regulatory agency inspectors, being user-friendly, having access to components to be tested, allowing no damage to the hoist, and being acceptable to mine operators. In this context the parameters specified by the contract were investigated, as well as additional parameters deemed to be important in the determination of compliance with CFR 30 regulations and the operational status of a mine hoist electrical system. These parameters include :

(a) System currents, voltages and speeds.
(b) System accelerations, decelerations, distances travelled and peak values.
(c) System drive motor powers and torques.

As a consequence of measuring these parameters, other useful information concerning the operational status of the hoist was revealed and is only dealt with briefly in this report.

The investigation yielded a basic test instrumentation installation procedure and a series of inspection tests to obtain data in the most efficient manner. These are in the form of flowcharts, which guide an inspector through methods for determining what test equipment should be used, where it should be installed and the number required. The inspection test flowcharts guide an inspector through each of the suggested tests.

It is the objective of this report to study and recommend definitive design considerations for an automated method to gather hoist control parameters and perform analysis.

2. RESEARCH METHODOLOGY.

2.1 Personnel.

It is proposed that this system will be used principally by mine inspection personnel, electricians, and engineers. It is recommended that initially the inspection methods and instrumentation be used by engineers of MSHA Technical Support Center. The level of ability for users of the proposed system required some study into the complexity of the inspection methods and instrumentation. The inspectors will use the expertise of mechanical and electrical personnel located at the mine being inspected. However, a great cross-section of technical ability and education might be encountered in the mine situation.

Stemming from the varied levels of education possessed by persons that would use this inspection system, the following guidelines were established for determining inspection procedure and instrumentation :

a. All instructional material will be able to used by persons of limited technical knowledge.

b. The instrumentation should be easily installed by a mechanic or a mine electrician depending on the nature of the work required and that personnel of this type can be found at the mines.

c. Tests and data collection required to ensure compliance with the hoisting regulations (CFR 30) will be of foremost importance in the inspection procedure.

d. Additional testing procedures, data collection and instrumentation are recommended. These recommendations will complete the range of values which should be determined when assessing the safety of a hoist electrical system.

2.2 Information from manufacturers.

To determine whether certain data could be obtained by measurement, many sensor and transducer manufacturers were contacted. Information concerning certain instruments was not asked ; rather, how a measurement problem could be overcome was posed. This approach was to reveal methods of measurement not originally conceived by the investigators. The commercial availability of certain measurement techniques and instruments was determined, as well as their cost and availibilty. In addition, some instrument specifications were examined to determine possible use in the context required. Problems which might be encountered during measurement, were explained. It was decided that this might encourage the manufacturer to indicate possible ways of approaching these problems. They were asked not only for specific information concerning one measurement, but on all their measuring products as well. Other manufacturers of hoists, electric motors, hoist control systems and associated equipment were targeted.

Information requested would be used to gain a better insight into the systems for which inspection procedures and instrumentation were to be created. It was expected that literature from these manufacturers would comprise the following:

a. A general explanation of the operating principles of their product.

b. Recommended inspection and testing procedures for their products.

c. Detailed specifications for certain products.

d. Information concerning possible malfunctions in certain instrumentation and procedures. That is, how signs of a pending or already present failure could be detected and what measures could be taken to avoid these pitfalls.

2.3 Mine visits.

The contract made provision for seven mine visits. The philosophy behind choosing the mine hoists to be visited, was the following:

a. The age range of hoists, from the oldest to the most modern hoist.

b. The most simplistic, bare essentials type of hoist. This should most likely occur in the very small mine situation.

c. The most sophisticated hoist, with regard to its design and operation, i.e., state of the art in hoisting.

d. As many different generic type of hoists as possible.

This group was to be made up of the following types and illustrated in figures 2.1 to 2.9.

i. Single cylindrical drum - single rope.
ii. Single cylindrical drum - double rope.
iii. Double cylindrical drum - double rope.
iv. Single conical drum - single rope.
v. Bi-conical drum - double rope.
vi. Double conical drum - double rope.
vii. Ground mounted friction hoist.
viii. Tower mounted friction hoist.
ix. Single cylindrical drum slope hoist.

e. A range of hoist electrical configurations. From DC generation by motor generator set, to micro-processor control SCR generation of DC, as well as AC and DC motor control systems of differing method and sophistication.

f. Hoists with equipment made by many different manufacturers. This

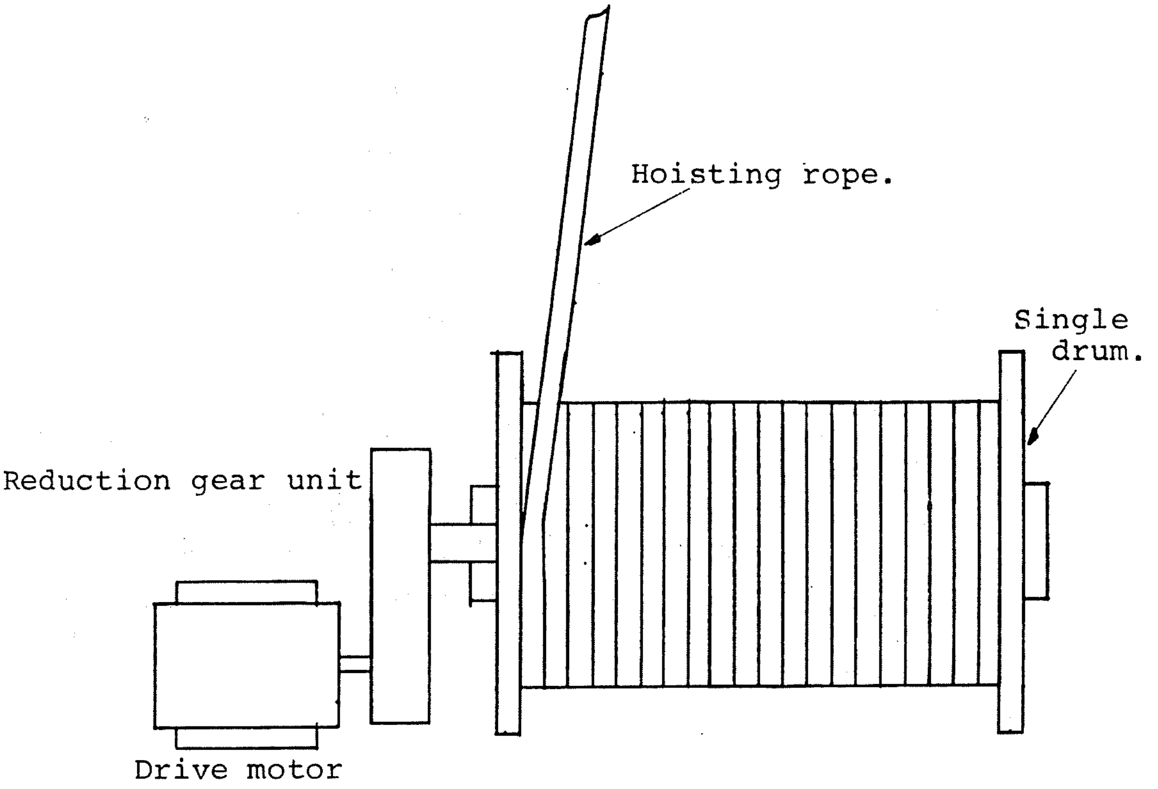

Figure 2.1 - Single cylindrical drum - single rope. Top view.

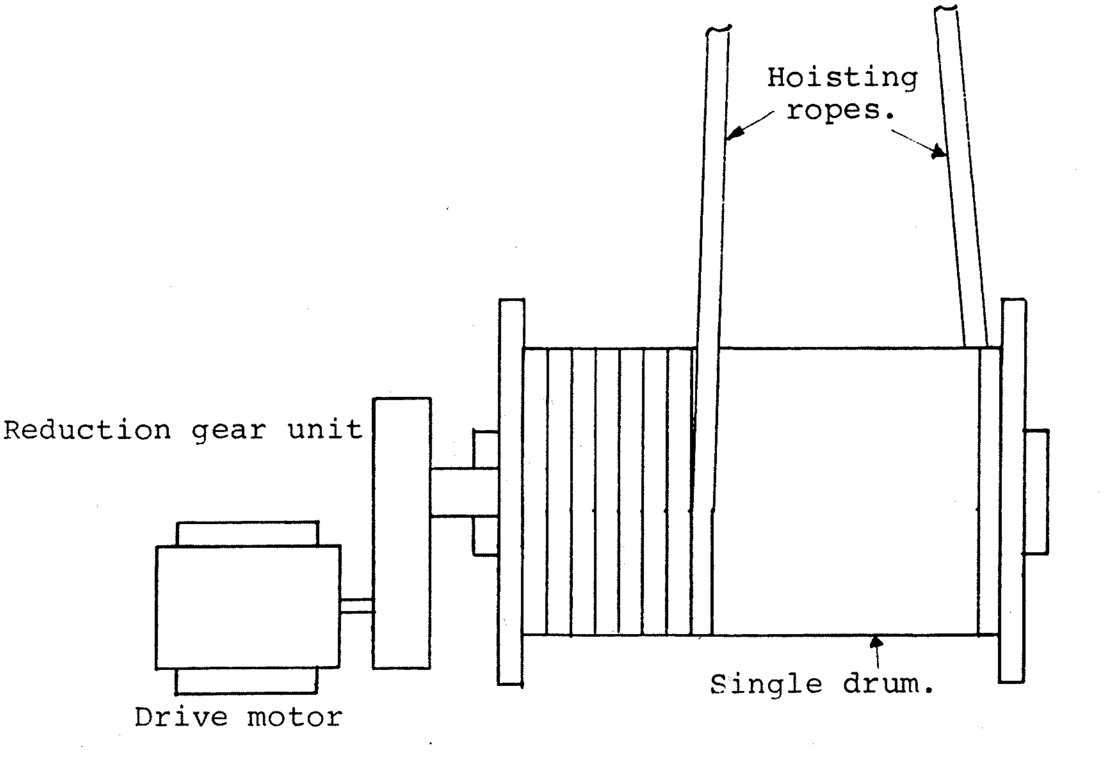

Figure 2.2 - Single cylindrical drum - double rope. Top view.

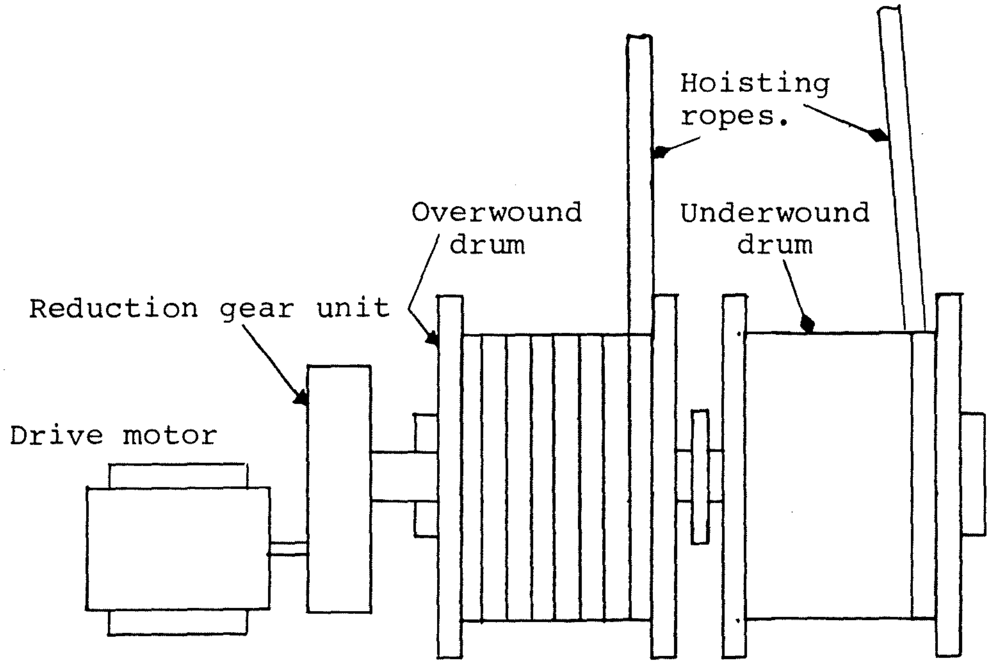

Figure 2.3 - Double cylindrical drum - double rope. Top view.

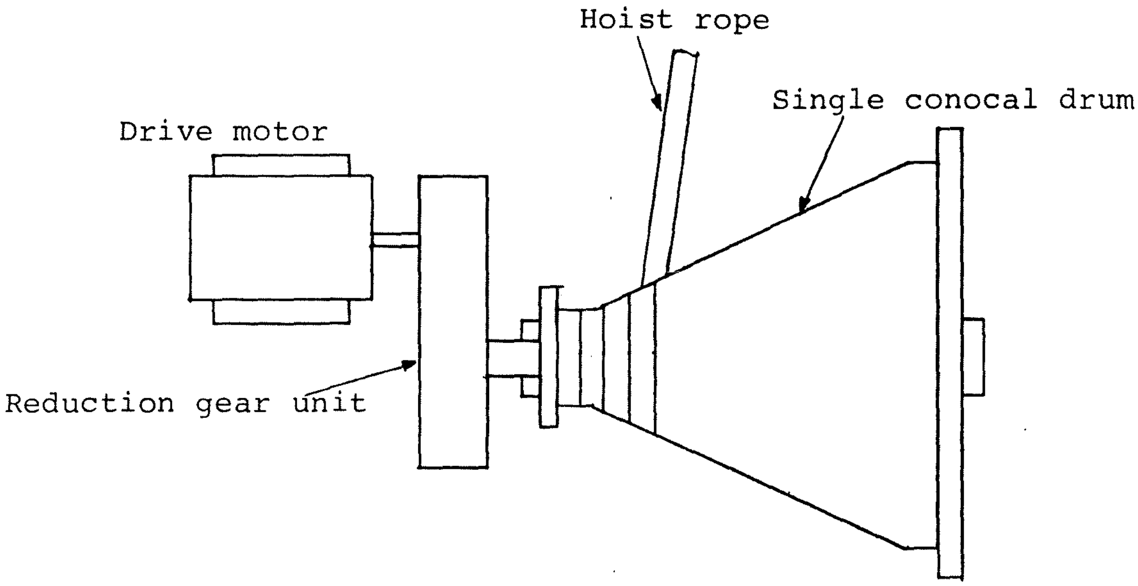

Figure 2.4 - Single conical drum - single rope. Top view.

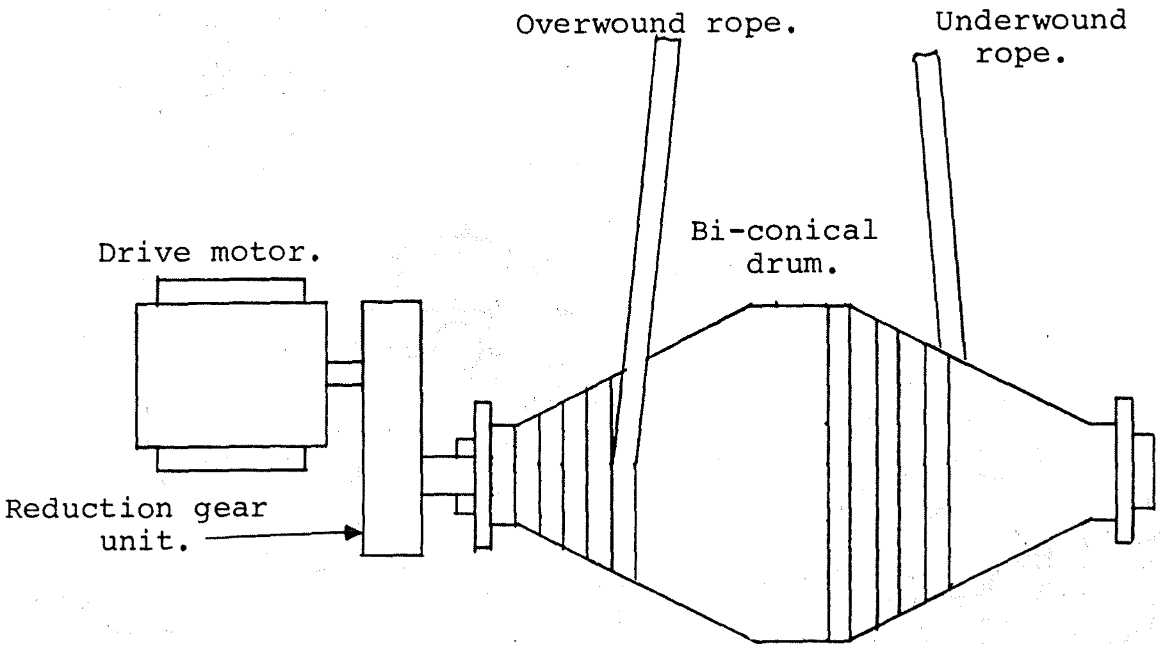

Figure 2.5 - Bi-conical drum - double rope. Top view.

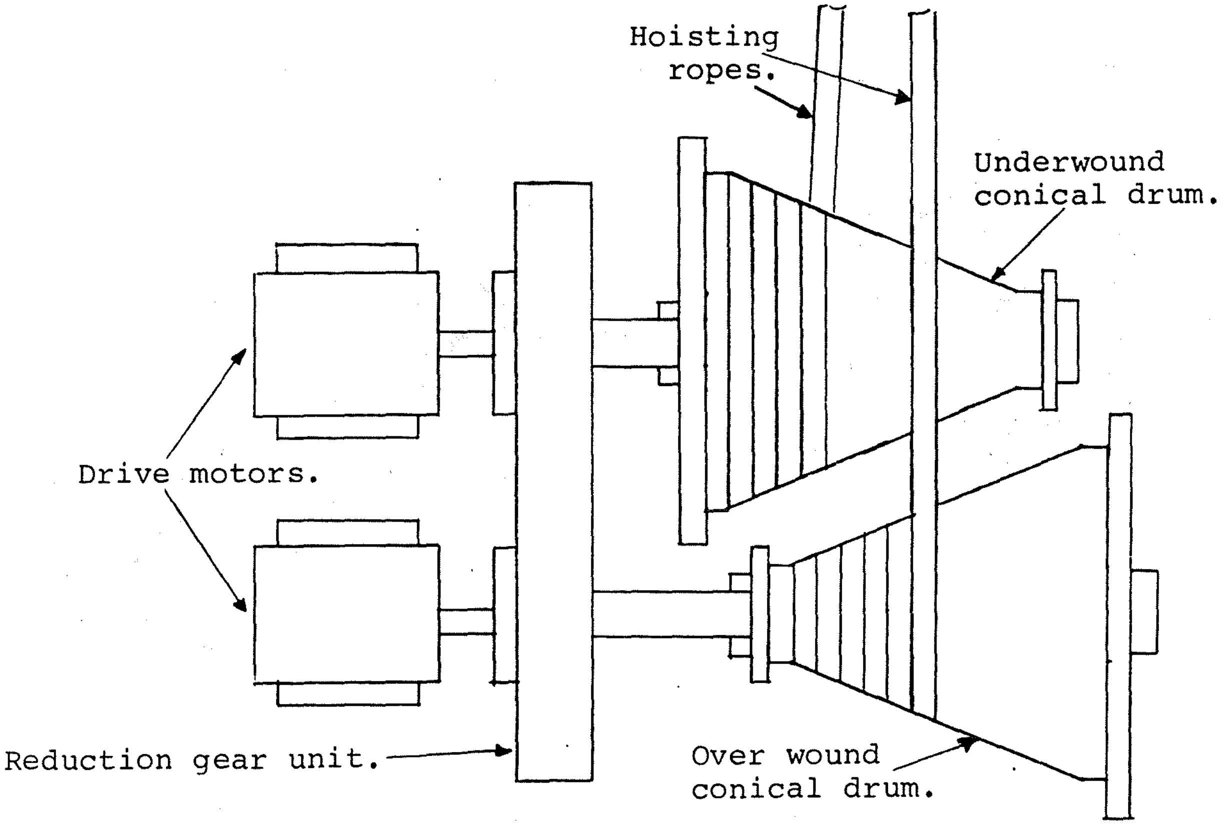

Figure 2.6 - Double conical drum - double rope. Top view.

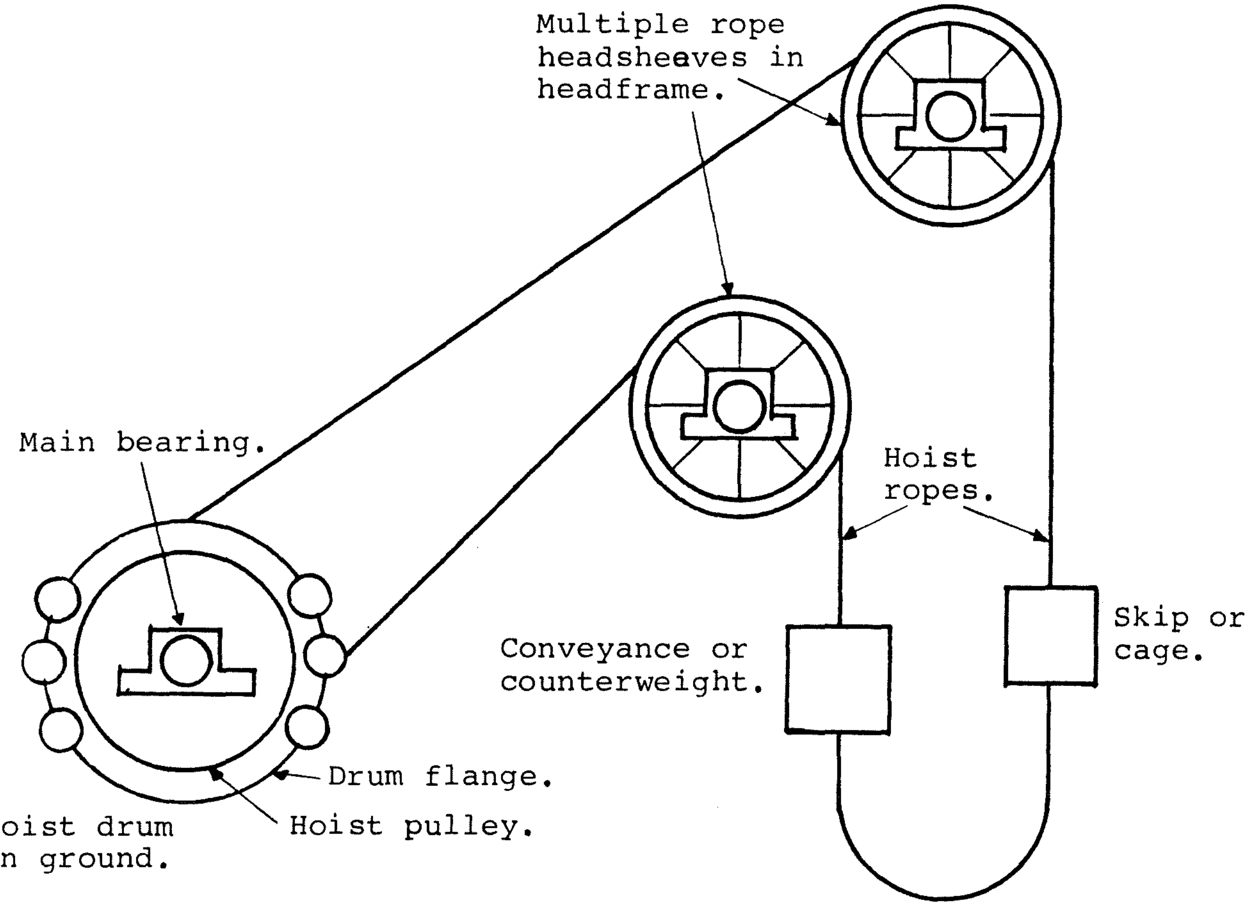

Figure 2.7 - Ground mounted friction hoist. Side view.

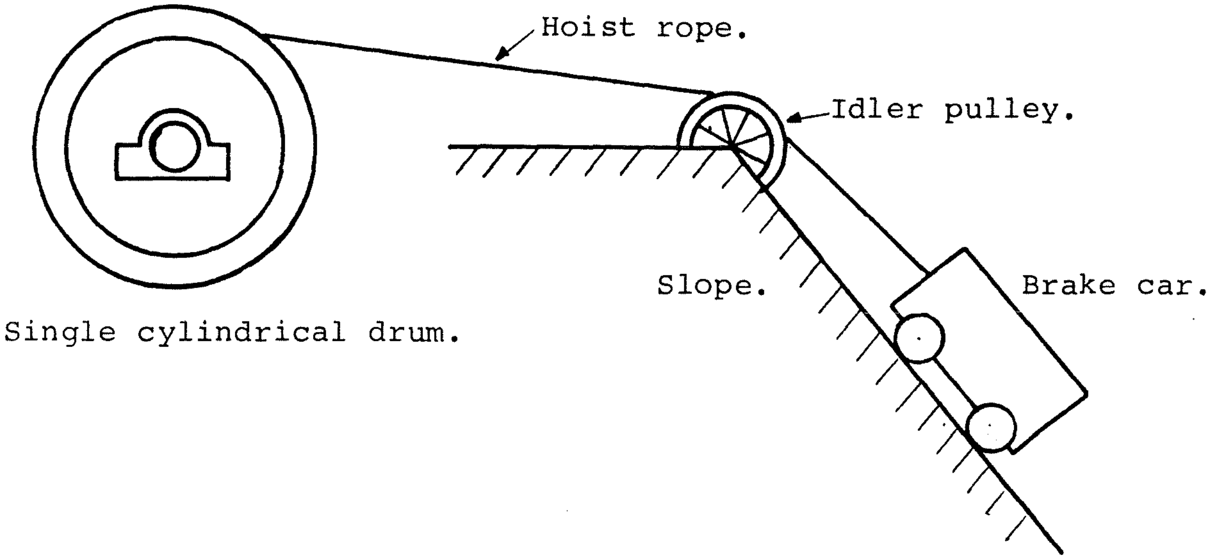

Figure 2.8 - Single cylindrical drum slope hoist with brake car. Side view.

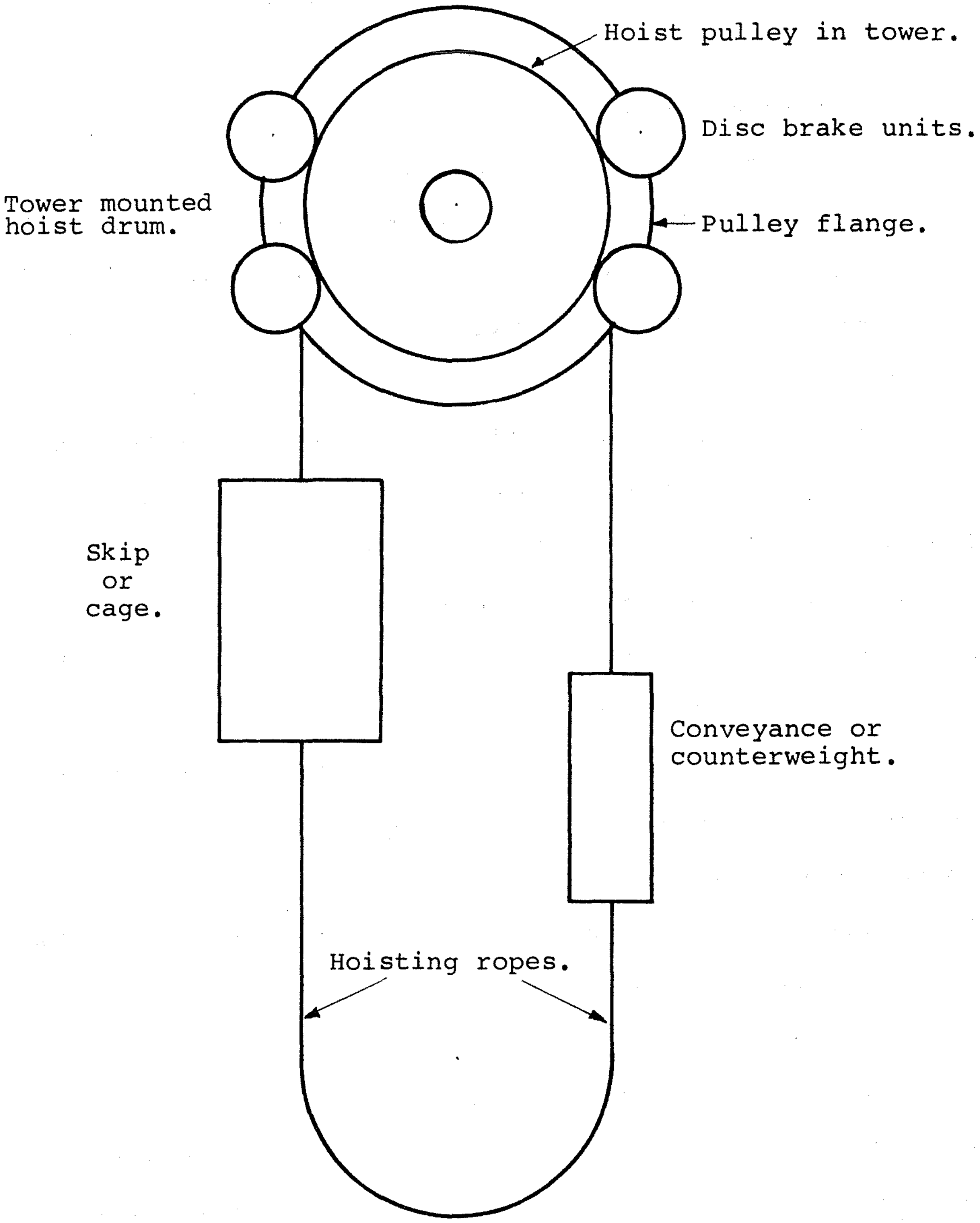

Figure 2.9 - Tower mounted friction hoist. Side view.

equipment should include hoist control systems for automatic hoists, mechanical "hoist controllers", hoist systems and configurations in general.

g. Vertical hoists and slope hoists.

h. Hoists located at coal and metal non-metal mines, note differences that might be present between these, and determine how these differences or similarities might affect the design of the proposed inspection system.

Once these types of hoists were defined, the important features to study during the visits were determined. As the visits continued new ideas concerning measurement procedures and instrumentation, were developed for more specific features of the hoists. The measurement points for the various proposed tests were envisioned. It was important to note where the tests and instrumentation could be applied. For every visit, the physical dimensions of equipment was noted, manufacturers names, age and performance attributes. Any other features which were unusual and warranted attention, were noted as well. Particular attention was paid to the electrical features of each hoist, any type or form of control system present, existing instrumentation, and any other safety features incorporated into the system.

2.4 Informative discussions.

It was thought to be beneficial that people and organizations involved in mine hoist electrical systems be contacted. Meetings were arranged to discuss the specialties of the persons involved. This approach enlarged knowledge and understanding of specialty topics and hoisting systems in general for the investigators. A better understanding of the persons who might use this type of inspection and testing system was gained. For these reasons the following catagories of persons were interviewed :

a. Typical MSHA mine inspector.

b. MSHA inspector versed in electrical and hoist inspections.

c. An MSHA elevator inspector.

d. Personnel involved in the MSHA Technical Support Division.

e. Persons with extensive Lilly con the MSHA Technical Support Division.

e. Persons with extensive Lilly controller experience.

f. Persons with design experience for hoists and hoist control systems.

g. Mine operators.

h. Mine maintenance personnel.

i. Manufacturers of electric motors, hoist control systems, etc.

j. Persons employed by sensor and transducer manufacturers.

2.5 Parameters, calculated values, conditions, etc.

The determination of a hoists operating condition can be attained by the examination of a group of variables which identify this condition. These variables must be obtained through the measurement and/or monitoring of performance attributes of the hoist. The identification of these variables is the first step in determining what performance attributes are to be measured or monitored. Once the measurement parameters have been indentified, the feasibility of their measurement must be determined, i.e., whether instrumentation technology to make the measurements is available at present. The feasibility question also requires a determination of whether it can be adapted to the mine hoist environment.

The development of which parameters should be investigated in this report can be split into several sections. The requirements of the USBM contract J0134006, regulations contained in CFR 30, and additional parameters stated in the investigators' technical proposal form the base of parameters. Additional parameters which are important in making a determination of the operational status of the mine hoist electrical system make up a second section. The third section consists of those parameters which are not related to the electrical system but concern the operational status of the hoist in general, and were obtained only as a consequence of determining the previous parameters. They are mentioned in this report in a cursory way.

The contract required that the following be investigated :

a. Current.
b. Voltage.
c. Speed.
d. Acceleration.
e. Deceleration.
f. Distance traveled.
g. Peak current.
h. Average current.
i. Peak voltage.
j. Power during acceleration.
k. Power during deceleration.
l. Torque requirements for various loads.
m. Motor shaft torque.
n. Distance traveled during an emergency stop.
o. Deceleration rate during an emergency stop.
p. Regulator response time.
q. Current limit settings.

r. Rope stretch.

s. Brake condition during repeated stops.

The technical proposal listed the following :

a. Elapsed time during acceleration and deceleration.

b. Grounded and grounding system condition.

c. Values during normal and abnormal (or emergency) conditions.

d. Values at the drum. (where applicable)

e. Values at the cage, bucket, skip where applicable.

f. Velocity (speed) of various components during varying conditions.

To determine compliance with CFR 30 regulations, the following were also investigated and reported for operation :

a. Emergency stop buttons.

b. Overtravel backout switch.

c. Overtravel bypass switch.

d. Clutch to brake interlock.

e. Overtravel protective devices.

f. Overspeed protective devices.

g. Hoist feeder power loss protection.

The following were considered important in making a determination of the operational status of the mine hoist electrical system :

a. Hoist control power loss protection.

b. Hoist DC drive motor field loss protection.

c. Time interval related studies, i.e., comparison of results from one inspection to the next.

A parameter not directly connected with the mine hoist electrical system, but mentioned in the report is the mechanical brake testing and setting.

2.6 Ladder diagram analysis.

To understand a control system, it was decided to analyze the ladder diagram of a small "homemade" hoist control system. The hoist consisted of a double drum, driven by an AC wound rotor induction motor. A relay and timer type controller was used for the acceleration and deceleration control as well as providing the external circuit for the Lilly controller and other safety features. The system was analyzed through the use of a computer program that simulated the ladder diagram. Thus, different inputs were provided to the program and the simulated response of the system was noted. In this way the expected reaction of the control system to various emergency situations could be found.

2.7 Hoisting accident investigations.

When a hoisting accident causes an injury or a fatality, a report must be filed with MSHA. These reports generally contain the nature of the accident and its effects. In the case of a fatality, an investigation is carried out by members of MSHA. They write another report in which a probable cause for the accident is cited, if one is found. The contents of these reports was a very useful source of information. By studying the accident descriptions, the following information would be gained :

a. What types of electrical system, control system, or safety feature failures caused accidents.
b. Was any form of accident more prevalent than another.
c. What actually caused the accident.

This information would help establish what parameters should be investigated during an inspection.

2.8 User-friendly instrument installation flowcharts.

The previous sections describe the methods to determine the instrumentation to be used to measure electrical performance parameters, and the location of their measurement points. The next problem was to find the most effective method of guiding an inspector through the selection and installation of instrumentation. Instruction in this area is necessary due to the variation in physical layout in hoisting systems. The most effective method of instruction was determined to be instructional type flowcharts. The flowcharts do not specify installation procedures, but give the inspector a determination of the instrumentation to be used, where it should be installed and the number of instruments required. The flowcharts further instruct the inspector for the personnel required for this installalation and what to do when measurement is either difficult or impossible.

2.9 Set-up of performance tests.

The most effective and efficient manner of collecting these measurements is to move the hoist through a group of performance tests. These tests are sequenced to limit downtime and prevent further tests if test results indicate an unsafe condition. As with the instrumentation it was determined that the best way of guiding the inspector through the tests was a group of flowcharts. These will guide testing sequence and the instructions during each test. The test system will automatically determine what measurements are needed during each test.

3. HOIST PERFORMANCE CRITERIA

3.1 Determination of parameters.

3.1.1 Current.

Current can be determined through a direct measurement of this parameter. This applies to both DC and polyphase AC.

The instrument most suited for AC or DC measurements is a "clamp-on" current sensing device.

The methods used for current measurement will differ depending on the nature of the current involved, i.e. direct current or alternating current. In the case of direct current measurements for devices such as motors, the line and return current from that device will be measured. When measuring three phase currents the three different phase currents will be measured separately. At least three sensors will be used for each measurement. Of the three readings taken, at least two will be within tolerence of the sensors. The system will then "average" the two closest readings for the most true value of the measurement.

3.1.2 Voltage.

Voltage can be directly measured whether it is direct or alternating.

The instrument most suited for AC or DC measurement of voltage is a "clamp-on" voltage sensor.

As with current, the methods used for the measurement of voltage depend on the its nature. When measuring DC the voltages across the device under consideration will be measured. The three line to ground (neutral) and the three line to line voltages will be separately measured when working with three phase AC. At least three sensors will be used for each measurement. Of the three readings taken, at least two will be within tolerence of the sensors. The system will then "average" the two closest readings for the most true value of the measurement.

3.1.3 Conveyance speed.

There are several ways of determining conveyance velocity. The first is by a direct measurement on the conveyance. The direct measurement of conveyance velocity is taken from a wheel tachometer that is mounted on the conveyance with the wheel riding on the shaft guides. The data will not be transmitted to the surface but stored by a data aquisition system mounted on the conveyance. At least three wheel tachometers will be used for this measurement. Of the three readings taken, at least two will be within tolerance of the sensors. The system will then "average" the two readings closest to each other for the most true value of the measurement. Comparisons with velocity values obtained from the hoist drum angular velocity measurements, will provide an additional check.

Second, an indirect method, where velocity is calculated by differentiating displacement over time, or integrating acceleration over time. This can be seen in expressions 1.3a and 1.3b below :

$$S = d(d)/dt = \Delta d/\Delta t \qquad \text{- 1.3a}$$

$$S = \pm\int (a)\,dt \qquad \text{- 1.3b}$$

Where : S = Conveyance velocity.

d = Conveyance displacement.

t = Time.

a = Conveyance acceleration.

The values of delta d and delta t can be taken from the continuous conveyance distance measurement. The conveyance velocity can also be determined by continuiously measuring the angular velocity of the hoist drum. This method is explained in section 3.4.7.

3.1.4 Conveyance displacement.

Conveyance displacement can be determined by a direct measurement, integrating conveyance velocity over time, or by the double integral of conveyance acceleration over time. This indirect method can be quantified by expressions 1.4a and 1.4b shown below :

$$d = \int (s)dt \qquad -1.4a$$

$$d = \pm\int\int (a)dtdt \qquad -1.4b$$

Where : d = Conveyance displacement.

s = Conveyance velocity.

a = Conveyance acceleration.

Values of d and s can be obtained from the continuous conveyance velocity and acceleration/deceleration measurements respectively. The direct measurement of conveyance displacement is taken from a wheel odometer that is mounted on the conveyance with the wheel riding on the shaft guides. The data will not be transmitted to the surface but stored by a data aquisistion system mounted on the conveyance. At least three wheel odometers will be used for this measurement. Of the three readings taken, at least two will be within tolerence of the sensors. The system will then "average" the two closest readings for the most true value of the measurement. Comparisons with displacement values obtained from the hoist drum rotational displacement measurements, will provided an additional check.

Another method of determining conveyance displacement is by counting hoist drum rotations. If the circumference of each layer of rope on the hoist drum is known, the amount of rope displaced from or onto the drum can be easily calculated. The amount of rope displaced off the drum is then equated to the displacement of the conveyance. However, rope stretch or conveyance hang-up will cause the calculated value to be in error. As the conveyance is lowered, this error increases in magnitude due to increased rope stretch.

3.1.5 Conveyance acceleration and deceleration.

Conveyance acceleration and deceleration rates can be measured directly, and verified by differentiating velocity with time or doubly differentiating displacement with time, as shown in expressions 1.5a and 1.5b below :

$$a = \pm d^2 (d)/dt^2 \qquad -1.5a$$

$$a = \pm d(s)/dt \qquad -1.5b$$

Where : a = Conveyance acceleration (or deceleration.)

d = Conveyance displacement.

s = Conveyance velocity.

The values of d and s can be obtained from the continuous conveyance displacement and velocity measurements respectively. Conveyance acceleration and deceleration rates will be measured directly with the tri-axis accelerometer/decelerometer. The data will not be transmitted to the surface but stored by a data aquisistion system mounted on the conveyance. At least three accelerometer/decelerometers will be used for this measurement. Of the three readings taken, at least two will be within tolerence of the sensors. The system will then "average" the two closest readings for the most true value of the measurement. In addition, acceleration and deceleration rates calculated from the conveyance displacement and velocity measurements will be used as redundant checks on the device readings. The deceleration vs time profiles that can be created from these measurements can be used in brake performance testing and setting. (2) (3)

A crude check of the conveyance acceleration and deceleration rates can be obtained through the measurement of hoist drum angular acceleration and deceleleration rates. These values can be used to calculate rope acceleration and deceleration rates at the drum. However, the elastic properties of the rope have in some cases been shown to cause the conveyance acceleration and deceleration rates to differ from those measured from the hoist drum by a factor as large as two. (2) This is therefore not a reliable technique.

A tri-axis accelerometer/decelerometer is the best instrument to use. For its associated sensors, and transducers see section 4.3. All conveyance acceleration calculations requiring derivatives will be executed using software incorporated in the test system.

The results of high conveyance acceleration and deceleration rates encountered in man cages during normal and emergency operating conditions, can cause severe injuries to personnel travelling on that conveyance. Undue stress can also be applied to the rope and conveyance which could eventually lead to their failure. Regulations contained in CFR 30 (metal/non-metal 57.19-62) specify that the maximum normal operating acceleration and deceleration shall not exceed 6 feet per second per second. The maximum deceleration during emergency braking shall not exceed 16 feet per second per second. Measurements can be used for testing compliance with these regulations.

3.1.6 Drive motor power.

The methods used for drive motor power measurement will differ depending on the nature of the motor involved, whether AC or DC. In the case of DC drive motors, motor power will be determined through the continuous measurement of DC voltage and current to the motor. Current and voltage measurement are discussed in sections 3.1.1 and 3.1.2

respectively. These values can then be used to calculate power = voltage x current at any point in time during the operation. AC motor power can be directly measured using a power transducer. The active motor power in watts will be determined by a total power (all phases) transducer. At least three transducers will be used for this measurement. Of the three readings taken, at least two will be within tolerence of the sensors. The system will then "average" the two closest readings for the most true value of the measurement.

A representation of drive motor power during hoist acceleration and deceleration can be obtained using these measurements. These values can be used to check drive motor cycles in relation to assessing the drive motor size for the maximum payload operation. That is, if the rated capacity of the drive motor is below that required to operate the hoist safely, the hoist is out of complaince.(CFR 30, 57.19-1 and 77.1402) Drive motor power measurements taken during dynamic or regenerative braking can be used to determine the total power generated by the hoist during electrical braking.

3.1.7 Rope tension.

Hoist rope tension can be determined by direct measurement. Appendix 1 gives a detailed description of the theoretical aspects of this measurements.

There are several testing unit location where this measurement can be taken, depending on the hoist configuration encountered at a mine. Through observation of many different hoisting configurations the measurement locations have been narrowed down to two. These positions should allow rope tension measurement to be made at most hoists. Figure 3.1 shows the first and most desirable position. This position can only

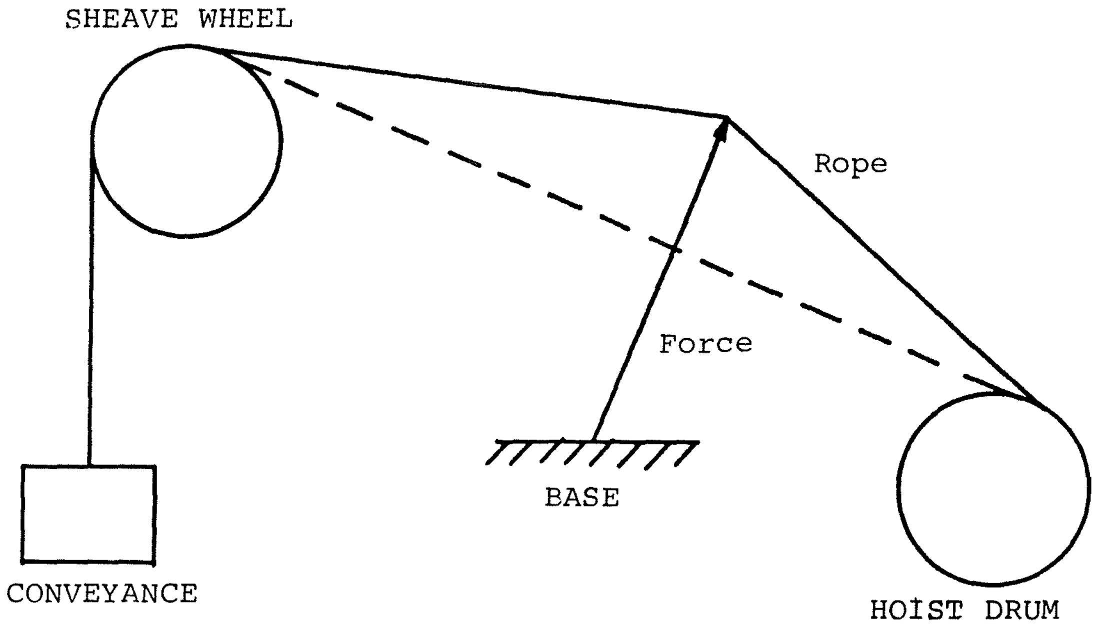

Figure 3.1 - Rope Tension Device - Position 1.

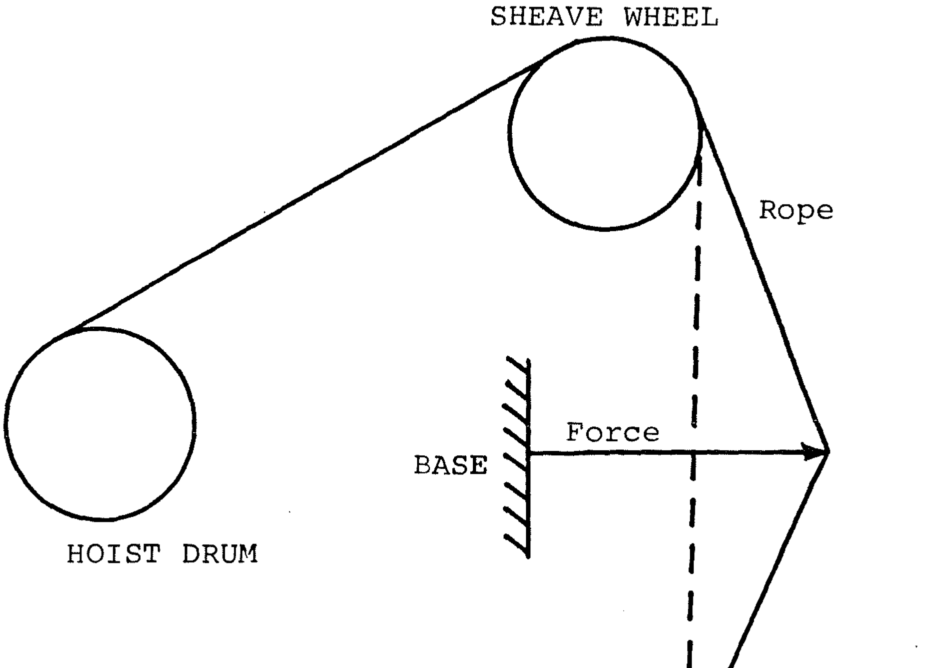

Figure 3.2 - Rope Tension Device - Position 2.

be used when the angle θ is small. As this angle increases the physical dimensions of the instrument must increase up to a stage where it becomes impractical to use. This position is also impossible to use for tower mounted friction hoists. The second measurement position is shown in figure 3.2. This position should be available at most hoists. Friction hoists are normally operated with multiple ropes. The rope tension measurement device will measure the total tension applied to all the ropes. The rope tension measured at different positions will differ, however it is not difficult to use these tension measurements to calculate rope tensions at other points.(see appendix 1)

3.1.8 Regulator response time.

Regulator response time is the time between the signal for regulator action and that action. For an emergency stop condition, the regulator response time would be the time between detection of an emergency condition and initial movement of the brake pad. Brake contact response time is the time between detection of an emergency condition and the application of the hoist mechanical brakes. The application of brakes can be defined as the first contact of the brake pad with the drum or disc. Reference (2) indicates that for a modern spring applied braking system the brake contact response time should normally be in the order of 300 to 400 milliseconds, and for a dead weight applied braking system not more than 1.5 seconds. Extreme differences between the actual brake response time and these values could indicate a possible regulator adjustment, repair or a design flaw. The brake contact response time includes the so called brake lead-in time. The two different response times can be expressed as the following :

Brake contact response time = (brake pad contact with drum or disc time) - (emergency condition detection time)

Regulator response time = (initial brake pad movement time) - (emergency condition detection time)

The times listed in the expressions above can be easily determined by continuously monitoring brake pad movement and the devices used to detect emergency conditions.

Brake pad movement will be detected using an accelerometer placed on the pad. When the pad starts to move the value of acceleration will increase suddenly from zero. When the brake pad comes into contact with the drum the brake pad will decelerate very rapidly. A typical accelerometer tracing might resemble that shown in figure 3.3. In addition the device to be used to initiate an emergency condition must be monitored. Emergency stop buttons, overtravel protection devices, and overspeed protection devices are examples of such devices. The monitoring of voltage across this device will indicate the time that device was triggered. The test system will be equipped with an internal clock. The accelerometer and voltage readings will be analyzed by the system, and the times required will be determined.

3.1.9 Mechanical drive motor shaft torque.

Mechanical drive motor shaft torque can be determined by directly measuring the torsional deflection of the shaft. Applied torque T can then be calculated using the expression below :

$$T = \frac{\theta \pi C D^4}{32L}$$

Where : L = Shaft length.

D = Shaft diameter.

C = Modulus of shaft rigidity.(elasticity)

θ = Deflection angle.(twist)

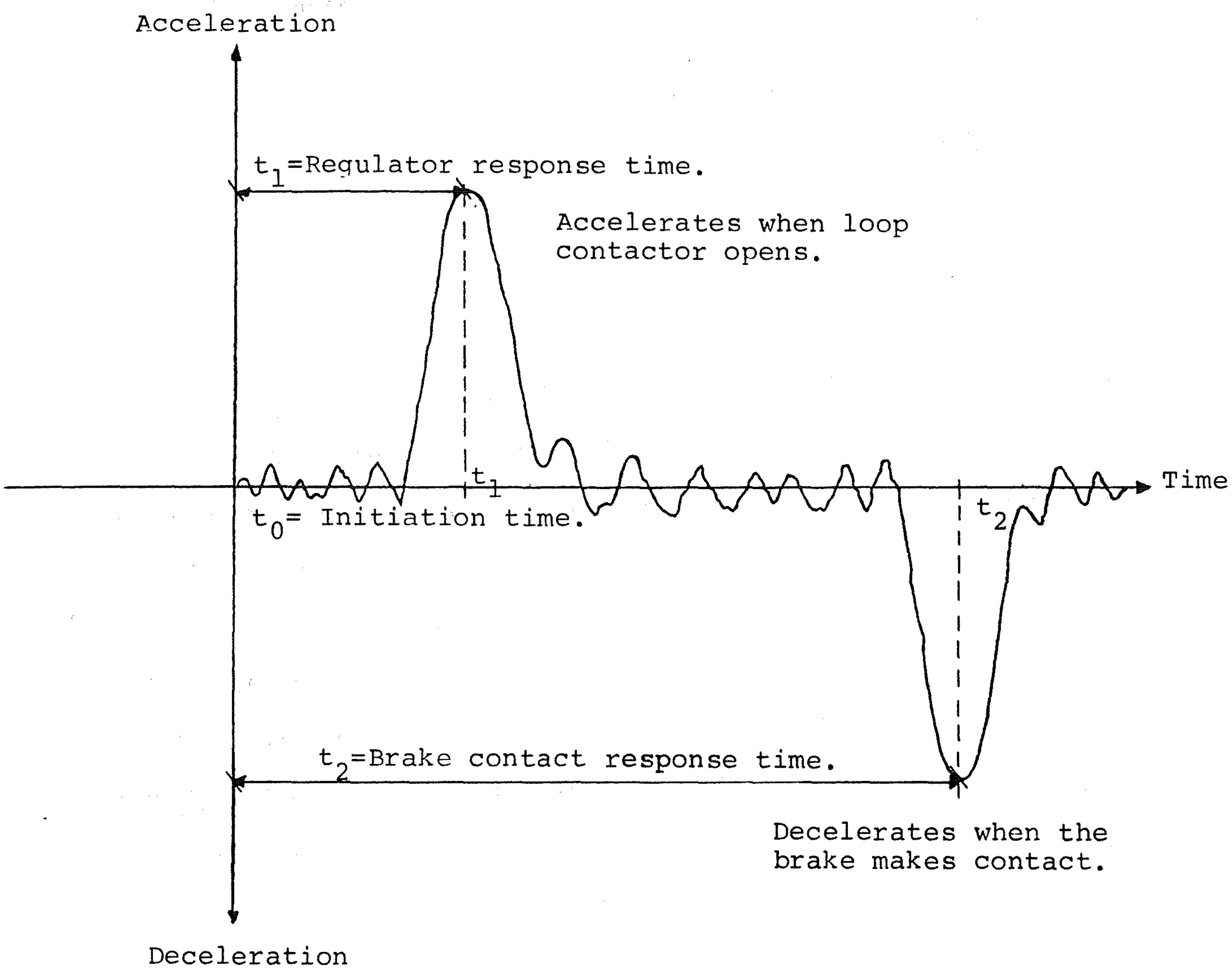

Figure 3.3 - A typical brake pad accelerometer tracing.

The angular torsional deflection can be measured using several different techniques. The most common of these are :

a. Strain gages.

b. Differential transformer.

c. Variable permeability.

d. Phase method.

e. Optical method.

Techniques a thru e are discussed in reference (7).

All these techniques require knowledge of some of the physical properties and dimensions of the motor shaft. In many cases the modulus of shaft rigidity will be unavailable due to the age and unknown origins of the motor. In addition, they require instrumentation that is difficult and time consuming to install, as well as being permanent in nature. These drawbacks make them unacceptable within the measurement philosophy set out in section 4.5. Mechanical drive motor shaft torque will therefore not be determined using these methods, however an alternative method is shown in section 3.1.7.

3.2. CALCULATED VALUES.

3.2.1 Peak current.

The peak current can be found from the current measurements taken during a test. These would be digitized and recorded. When required, the data from the current measurements will be analysed by software for peak current determination.

3.2.2 Peak voltage.

As with peak current, the peak voltage will be determined using software incorporated into the testing hardware. The voltage measurements taken during a test will be digitized and recorded. When required, the data will be analysed for peak voltage determination.

3.2.3 Average current.

The average current will be determined by the expression below using software incorporated into the test equipment. The current measurements taken during a test would be digitized and recorded. When required, the data will be incoporated for average current determination.

$$i_{average} = 1/(t_2 - t_1) \int_{t_1}^{t_2} i(t)dt \qquad -2.3$$

Where : $i_{average}$ = Average current.

$i(t)$ = Instantaneous current at time t.

t_1 = Time reference.

t_2 = Some time later.

$(t_2 - t_1)$ = Time interval.

3.2.4 Electromagnetic torque - DC shunt motor.

The electromagnetic torque provided by a DC shunt motor can be expressed by the following :

$$T = k_1 \phi I_a \approx k_2 I_f I_a \qquad -2.4a$$

Where : T = Electromagnetic torque.

k_1 = Proportionality constant.

k_2 = Proportionality constant.

ϕ = Field flux.

I_a = Armature current.

I_f = Field current.

All the terms in expression 2.4a are not easily obtained. The proportionality constant k_1 is different and unique for every motor. It can be calculated from information obtained from tests and detailed information concerning the physical dimensions of the motor. The age and condition of the motor will in many cases cause the required detailed information to be unavailable. A measure of electromagnetic torque produced by the motor can be expressed by :

$$T_{measure} = I_f \times I_a \qquad -2.4b$$

It is a requirement of CFR 30 regulations (metal/non-metal 57.19-18), that the overtravel bypass device not release the brakes until sufficient drive motor torque has been developed to assure movement of the conveyance or counterbalance in the correct direction. The expression : $T_{measure} = I_f \times I_a$ gives a measure of electromagnetic torque. This can be used to determine compliance with the regulations.

3.2.5 Electromagnetic torque - AC wound rotor induction motor.

The electromagnetic torque provided by an AC wound rotor induction motor can be expressed by the following :

$$T \approx k_1 x(I_2^2/S) \approx k_2 x(I_2^2/f_2) \qquad -2.5$$

also, T is proportional to V_1^2

Where : T = Electromagnetic torque.

k_1 = Proportionality constant.

k_2 = Proportionality constant.

I_2 = Rotor current.

S = Motor slip.

f_2 = Rotor frequency.

V1 = Stator voltage.

All the terms in expression 2.5 are not easily obtained. The proportionality constants k_1 and k_2 are unique for every motor. These constants can be calculated from tests and detailed information concerning the physical dimensions of the motor. The age and condition of the motor can cause the required detailed information to be unavailable. A measure of the electromagnetic torque produced by the motor can be expressed by :

$$I_2^2 / f_2 \quad \text{and} \quad V_1^2$$

The determination of a measure of electromagnetic torque requires the measurement of the following :

a. The three line to line voltages.

b. The three line to ground (neutral) voltages, if available.

c. Three separate rotor currents.

d. Three separate rotor frequencies.

The measurement of three separate voltages, currents and frequencies as indicated above, inherently enables the most nearly correct value of these measurements to be checked.

It is a requirement of CFR 30 regulations (metal/non-metal 57.19-18), that the overtravel bypass device not release the brakes until sufficient drive motor torque has been developed to assure movement of the conveyance or counterbalance in the correct direction. The expression :

$$T_{measure} = I_2\,2 / f_2$$

or

$$T_{measure} = V_1\,2$$

gives a measure of electromagnetic torque. This can be used to determine compliance with the regulations. These measurements can also be used to determine possible faults (ground conditions) on the motor.

3.2.6 Rope stretch.

The elastic properties of the rope cause rope stretch when a load is applied and the amount of stretch will increase with load. As the conveyance is lowered the stretch increases. At any point in the shaft the amount of rope stretch can be expressed as the following :

Rope stretch = (Actual conveyance location) - (Conveyance location measured by hoist drum rotations)

The rope stretch will be static or dynamic depending on whether the conveyance is stationary or moving. This expression does not hold for friction hoists. Slippage between the rope and the hoist drum causes the expression to be in error.

The determination of rope stretch requires the measurement of actual conveyance location (see section 3.1.4) and the number of hoist drum rotations. The circumference of each layer of rope on the hoist drum is known and the amount of rope displaced from or onto the drum can be easily calculated. The amount of rope displaced off the drum is then equated to the displacement of the conveyance. By continuously monitoring actual conveyance location and calculating conveyance location by the hoist drum rotation method, the difference will yield rope stretch.

3.2.7 Hoist drum torque for various loads.

The torque exerted by the hoist drum on the hoist rope can be expressed by the following expression :

Torque = (Radius of drum) x (Rope tension)

Where the drum radius is the radius of that layer of rope on the drum, and rope tension is the tension there.

The hoist rope tension at the hoist drum must be determined (see section 3.1.7), and the radius of the drum must be measured. If the diameter of the rope is known then the radius of each layer of rope can be calculated. The continuous measurement of rope tension will enable the torque to be calculated at required times.

3.3 CONDITIONS.

3.3.1 Drive motor field loss.

The loss of field to a DC shunt-wound motor should cause an emergency stop. If the hoist is not stopped the motor could overspeed and self destruct. To test the hoist system response to a field loss, the field will be removed during the drive motor field loss test. The test will be performed when the hoist is not in operation, but the motor is powered. An emergency stop button should be activated immediately if the hoist control system does not itself initiate an emergency stop when the field is de-energized. Monitoring the field voltage will determine the state of the field, that is, energized or de-energized. The exact time of field loss can then be determined.

The field loss test will indicate whether the hoist is protected against a field loss condition. The emergency brake response time can also be determined. This time will indicate if the hoist response time to a field loss condition renders the hoist safe or unsafe. The electrical actions executed by the control system on initiation of an emergency stop, can be checked for correct sequencing and operation.

3.3.2 Control power loss.

There are several types of control power losses that can occur. They are loss of regulator control power, DC control power, or AC control power. The loss of power to any of these systems must initiate an emergency stop. In addition the regulator power should be monitored for undervoltage and overvoltage conditions as these conditions could cause the drive to lose calibration. This could cause the drive's speed, voltage or current to be significantly higher or lower than required. To test the hoist response to a control power loss, control power must be de-energized under controlled conditions. This test must be conducted while the hoist is stopped, but is still energized. The hoist motor currents and voltages, the control power and brake pad movement must be measured during the test. By monitoring the voltage of the control power supply, it can easily be determined if the control system is energised or not. The exact time of control power loss can then be determined.

The control power loss test will indicate if the hoist is protected against this condition. If the hoist is not emergency stopped when control power is lost, the hoist is unsafe. The emergency brake response time can also be determined. This time will indicate if the hoist's response time to a control power loss condition renders the hoist safe or unsafe. The electrical actions executed by the control system on initiation of an emergency stop, can be checked for correct sequencing and operation.

3.3.3 Feeder power loss.

Power outages suffered by mining companies are frequent, and the hoist must be stopped in the event of a feeder power loss. To test the hoist response to a feeder power loss, the feeder power must be removed under controlled conditions. The hoist is accelerated to test speed and then the feeder power is de-energised. Note that for M-G set controls it does not matter if the hoist is motoring or generating. With static drives, the hoist must be motoring during this test to avoid damage to the static drive. The hoist motor currents and voltages, the feeder voltage and brake pad movement must be monitored during the test. The measurement of the feeder voltage will enable a determination of whether the system is energised or not and the exact time of power loss can then be determined.

The feeder power loss test will indicate if the hoist is protected against this condition. If the hoist is not emergency stopped when feeder power is lost, the hoist is unsafe. The emergency brake response time can also be determined. This time will indicate if the hoist's response time to a power loss renders the hoist safe or unsafe. The electrical actions executed on the initiation of an emergency stop, can be checked for correct sequencing and operation.(see section 3.4.2)

3.3.4 Overtravel.

Overtravel is the movement of the conveyance past points in the shaft that define the ends of safe travel within that shaft. Uncontrolled movement of the conveyance beyond this area is considered to be dangerous and should initiate an emergency stop. This condition occurs near the bottom of the shaft (sump), or the top of the shaft (headframe).

There are several devices that can be used to detect an overtravel condition.

a. Limit switches mounted at the bottom and top of the shaft.
b. A Lilly controller.
c. A cam or programmed-type limit switch, which is driven from the hoist drum.
d. A programmed controller.

It is common to find several of the devices (a,b,c, or d) installed at a hoist. To evaluate the overtravel protection present on a hoist, the operational status of each of the devices present must be determined.

Determination of an overtravel condition requires knowledge of the exact location of the conveyance in the shaft at all times. Conveyance location must therefore be continuosly monitored as well as each of the protective devices present. This can be achieved by measuring the voltage at the protective devices. A sharp change in this voltage magnitude will indicate the triggering of that device. The exact conveyance location and time the device was triggered will be known. To create an overtravel condition the conveyance must be moved at the lowest possible velocity towards the headframe or sump. If no emergency stop occurs the conveyance must be stopped manually before reaching the limits of travel. The measurements taken during this test will indicate whether the hoist is correctly protected against overtravel.

Regulations contained in CFR 30, (metal/non-metal 57.19-7 and coal 77.1401) require that all man hoists be equipped with devices to prevent overtravel. Compliance with these regulations can be checked using this performance test. The following information concerning the operation of the overtravel devices on the hoist can be developed :

a. Which of the devices were operational.
b. Which device provides the primary overtravel protection and its location.
c. Whether the primary protective device initiated an emergency stop.
d. The system emergency brake response time on change of state for any of the protective devices.

It is common to find interlocks that prohibit the hoist from moving further into overtravel. This makes testing of secondary and tertiary overtravel protection difficult.

3.3.5 Overspeed.

Overspeed occurs when the conveyance exceeds by a known percentage, the maximum previously set speed for that location in the shaft. The occurence of an overspeed condition should cause an emergency stop to occur. The typical trip curves for an overspeed condition are given in figure 3.4. The methods used to sense overspeed are many and varied. They range from a relay-fly-weight on the brake car in a slope hoist, to sophisticated micro-processor based systems. In many cases the system contains more than one overspeed device. It is important in such a system that the so called redundant devices also be inspected for proper operation. The device that is most commonly installed to ensure overspeed protection is the Lilly controller. To evaluate the overspeed protection present on a hoist, the operational status of each of the devices must be determined if possible.

Determination of overspeed requires the measurement of two parameters. These are the location of the conveyance in the shaft, and velocity of the conveyance at that location. Figure 3.4, shows there are three regions of overspeed protection. They are static region (B-C) where the overspeed envelope is a constant speed and the two dynamic regions (A-B and C-D) where the overspeed envelope shadows the acceleration and deceleration sections of the profile. The overspeed protection envelope in all regions is most commonly situated between 10 and 15% higher than the maximum normal operating velocity.

Testing the overspeed protection for the static region is not difficult. In region B-C the conveyance is accelerated upwards until one of the overspeed devices is activated, causing an emergency stop to occur. However, if none of the overspeed devices is activated, the velocity must not exceed the maximum regulated velocity by more than 15%. If no emergency stop has been initiated before the 15% overspeed limit is reached, the hoist has no overspeed protection.

The dynamic regions A-B and C-D are located a short distance before

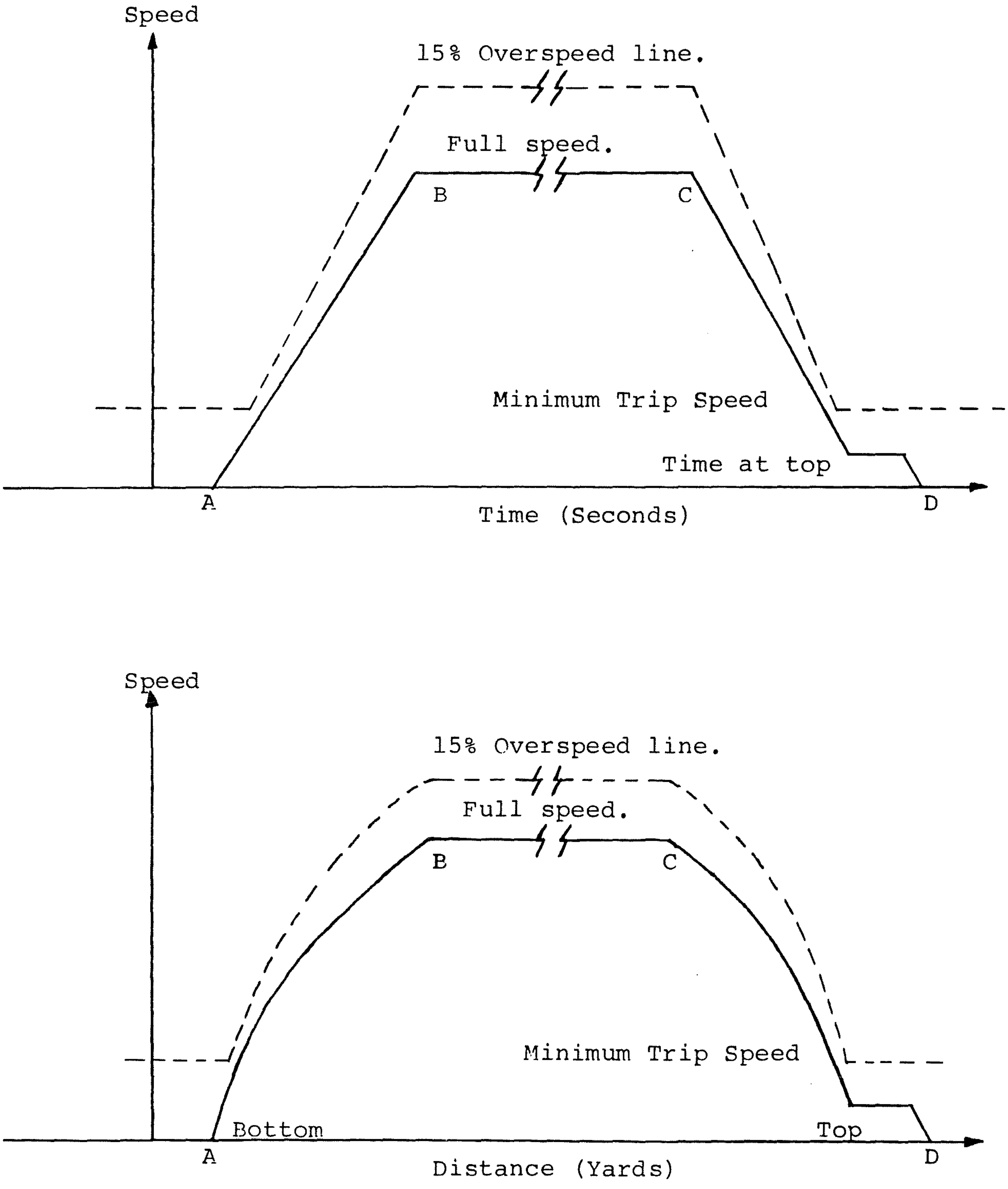

Figure 3.4 - Typical hoisting overspeed trip curves.

the conveyance travel limits. Overspeed protection in these regions can be tested by running the conveyance into overspeed, and plotting the overspeed protection envelope. However, if the overspeed devices are not operational and do not initiate an emergency stop, the conveyance will be hoisted into the headframe or lowered into the sump. This method is therefore undesirable.

It is common in many countries to test overspeed protection for the acceleration and deceleration regions, by creating a false landing at mid-shaft. The overspeed protection devices are reset with the deceleration or acceleration region now located at mid-shaft. The protection envelope can be determined without damaging the shaft or conveyance. These methods are extensively documented, and details concerning the set-up of a midshaft test and the evaluation of measurements taken from this test can be obtained from the following sources (2), (5). Source (4) has created a dynamic model that can be used to predict the actual overspeed protection envelope from results obtained during the mid-shaft tests. This model could be incorporated into the automated test system.

The overspeed devices must be monitored so that the exact time of each device triggering can be determined. Measurement of the voltage across the overspeed devices is the most suitable technique.

The methods discussed above hold for slope hoists as well as vertical hoists. However, slope hoists are required to have additional protection against overspeed. This is most commonly in the form of a fly-weighted relay that is directly coupled to one of the wheels on the brake car. This device is completely separate from the rest of the hoist machinery and when activated by an overspeed condition operates the electromagnetic brakes on the brake car. The state of this relay can be monitored by installing a voltage sensor across its contactors. The exact time, location and velocity at which the fly-weighted relay was activated can be determined. The data from the voltage sensors will be stored on magnetic tape located on the brake car.

Regulations contained in CFR 30, (metal/non-metal 57.19-7 and coal 77.1401) require that all man hoists be provided with overspeed devices. Compliance with these regulations can be checked using this performance test. The following information concerning the operation of the overspeed devices can be developed :

a. Which of the devices were operational.
b. Which device provided the primary overspeed protection and the conveyance velocity during overspeed.
c. Whether the primary overspeed device initiated an emergency stop.
d. The system emergency brake response time on change of state of any of the protective devices.
e. The overspeed protection envelope provided by the protective devices.

The overspeed protection for different points in the shaft can be determined from e.

3.4. MISCELLANEOUS.

3.4.1 Normal operating cycle test.

The normal operating cycle test will always be the first test conducted during an inspection. The primary objective of this test is to check the operation of all the instruments being used and the inspection system in general. Anomalies in the shaft will be revealed in this test so that they can be accounted for in the tests that follow. Instrument check procedures will be carried out by the inspection system during this test. The presence of faulty equipment, instrument misadjustment, or incorrect installation will be detected.

All instruments and transducers will be enabled during this test. The hoist operator will take the hoist through three complete hoisting cycles. One cycle being movement of the conveyance from the collar to the lowest level and back again. The inspection system will then indicate if further cycles are required.

3.4.2 The emergency stop buttons.

Regulations contained in CFR-30 (metal/non-metal 57.19-17 and coal 77.1401), require that each electric hoist be equipped with a manually operated switch that will initiate an emergency braking action. This switch must be located within reach of the hoistman and when operated, bring the conveyance and the counterbalance safely to rest. It is normal to find more the one emergency stop button on a hoist. The operation of each button must be tested individualy.

An emergency stop button of a different nature often exists on the brake car in a slope hoist. This button when pushed should operate the electromagnetic brakes on the brake car. It is important that the operational status of this button be determined.

To test the hoist response to the manual operation of an emergency stop button, the button must be operated under controlled conditions. The hoist is accelerated to creep speed and when the conveyance reaches a location just above the lowest landing the emergency stop button is pushed. This is then repeated for each button. When pushed the emergency stop button should initiate a sequence of predetermined events. It is common to have all the devices that can activate an emergency stop be wired into a series hoist safety stop circuit. Therefore an emergency stop triggered by any one of these devices should initiate the same sequence of events to bring the hoist to a stop. There are several techniques used in emergency braking. The most common is for the DC motor armature loop to be opened, and the mechanical brakes to be set. In more modern hoists, regenerative or dynamic braking is also used in the emergency braking process. Regenerative or dynamic braking is used between the time the emergency stop was triggered and mechanical braking is effected. At this point electrical braking can be removed or continued. In order to determine whether the proper sequence of events actually occured, the following should be monitored : the hoist drum and motor velocity, the motor currents and voltages, and the mechanical brake pad movement. In addition, the voltage across the emergency stop button will be monitored to determine exact time of operation.

When inspecting a slope hoist, the operation of the emergency stop button located on the brake car should be tested in the same manner as suggested for vertical hoists. However, to operate the button someone must be onboard the brake car. The voltage across the emergency stop button will be measured to determine exact time of operation. It would also be possible to activate the emergency stop button by remote control.

The individual events that occur during the stop, such as application of electrical braking, de-energizing the DC motor field, the movement of the mechanical brakes, etc, can be individualy evaluated for safe operation as well as emergency brake response time. This time will indicate if the hoist response time to the activation of an emergency stop button renders the hoist safe or unsafe.

3.4.3 The clutch to brake interlock.

It is a requirement of CFR 30 regulations (metal/non-metal 57.19-5 and coal 75.1403-3a), that all man hoists be provided with an interlock between the clutch and the brake, to prevent accidental withdrawal of the clutch during a free-drum condition. The interlock can be in the form of a locking mechanism, or an electrical or mechanical interlock.

To test the correct operation of an electrical clutch to brake interlock, a performance test will be executed under controlled conditions. The conveyance is chaired at a convenient location in the shaft. The brakes are then removed from the drum to be clutched, immediately followed by an attempt to remove the clutch. If the clutch is withdrawn we conclude that the clutch to brake interlock has failed, or does not exist. The movement of the clutch can be monitored visually during this test. This test will determine compliance with CFR 30 regulations. (metal/non-metal 57.19-5 and coal 75.1403-3a)

3.4.4 The deadman overtravel bypass switch.

It is a requirement of CFR-30 regulations (metal/non-metal 57.19-18), that when an overtravel by-pass switch is installed, the switch shall function so as to allow the conveyance to be moved through the overtravel position when the switch is held in the closed position by the hoistman. The switch shall then automatically return to the open position when released by the hoistman.

The operational status of this switch can be determined using several performance tests. The overtravel bypass switch is operated and the conveyance is lowered or hoisted into the overtravel position. Overtravel tests (see section 3.3.4) will have determined the location of the overtravel protection points. The hoist must then pass through these points without causing an emergency stop. Once the overtravel protection points have been cleared, the operator will release the bypass switch. At this time the hoist must perform an emergency stop. If either of the actions required by the test are not performed by the hoist, the switch can be considered to be operating incorrectly. This test must be conducted for both the overtravel and undertravel situation. This test determines compliance with CFR 30 regulation. (metal/non-metal 57.19-18)

3.4.5 The overtravel backout switch.

CFR 30 (regulation 57.19-83) requires that a "manually operated device be installed on each electric hoist that will allow the conveyance or counterbalance to be removed from the overtravel position. Such device shall not release the brake, or brakes, holding the conveyance or counterbalance until sufficient drive motor torque has been developed to assure movement of the conveyance or counterbalance in the correct direction."

The operational status of the overtravel backout switch can be determined by using a group of performance tests. These tests will be conducted in conjunction with the overtravel tests. After the conveyance has been lowered or hoisted into the overtravel protection and the hoist has been emergency stopped, the overtravel backout switch test can then be conducted. First, the backout switch is operated. An attempt is then made to take the conveyance further into overtravel. If this is possible the hoist must immediately be manually stopped, thus determining non compliance with regulation 57.19-83. If an emergency stop results from this action or the hoist will not release the brakes to move further into overtravel, the backout switch is operating correctly. Complete compliance with 57.19-83 is determined by the measurement of drive motor torque as discussed in section 3.1.9. The hoist can then be removed from overtravel and the backout switch returned to its normal operating position. This test can be used to assess compliance with CFR 30 (regulation 57.19-83).

3.4.6 Brake condition.

There are two different braking methods that are commonly used in mine hoisting. They are electrical braking and mechanical braking. Electrical braking consists of either dynamic braking or regenerative braking, and is the braking method most commonly used during everyday operation of the hoist. Mechanical braking has essentially three functions: first, to hold the drums stationary under maximum unbalanced load conditions; second, to help the operator in controlling the hoist under maneuvering conditions; third, to brake the hoist safely when conditions requiring emergency braking occur. The third function is the most difficult task for the mechanical brakes, especially with deep shafts where brake torque requirements vary over a wide range.

A determination of "brake condition" can be achieved using a variety of different methods of brake testing and inspection. Measurements can be taken at the hoist brake itself or on the conveyance, with each method providing valuable information concerning brake performance, brake settings, and the safe operation of the braking system. This topic is clearly beyond the scope of mine hoist electrical systems. However, measurements taken for the determination of other parameters can be used in the assessment of brake condition. This section will therefore not specify in detail the methods used for brake testing and inspection, but will reference papers where these details can be found.

3.4.6.1 Static brake tests.

These tests pertain to testing the holding capacity of the mechanical brakes. Braking torque requirements depend on the maximum allowed out-of-balance load and the inertia of all the moving parts. The total braking torque required is different with each hoist, however there is usually a close relationship between the braking torque required and the rating of the drive motors. References (1) and (7) specify what this relationship should be for direct coupled hoist and geared hoists, and also how static brake tests can be executed.

3.4.6.2 Dynamic brake tests.

Dymanic testing involves actually testing the performance of the brakes by causing the hoist to stop at different rates under a series of test conditions. Typically the following measurements are taken during dynamic testing conveyance speed, stopping time, stopping distance, location of conveyance, direction of movement, regenerative or dynamic braking currents and voltages, and conveyance deceleration rates. The advent of the conveyance mounted telemetering decelerometer has made the dynamic brake testing method extremely productive. The measurements made with this device can be used to determine the magnitude of brake deceleration rates, the combined effect of electrical and mechanical braking, rapid braking torque build-up and brake fade, and help determine the brake system adjustments required to counter the effects mentioned above. In addition, the decelerometer can be of value in detecting faulty shaft conditions such as guide misalignment, resonant conditions on the conveyance, and roller misalignment. Extensive information concerning the application of dynamic testing, the use of the telemetering decelerometer and the evaluation of their results can be found in references (1), (2), (3), (7), and (8).

3.4.6.3 Other brake condition tests.

It is common on many hoist to find brake fault detection systems. These are normally in the form of limit switches placed at strategic points on the hoist brakes, and when activated will cause an emergency stop of the hoist. Limit switches are often used for monitoring several conditions. If a loss of air or hydraulic pressure causes the brake weights to drop, this switch will be activated. The brake pad thickness is monitored, causing an emergency stop if the pad becomes too thin. Limit switches also monitor the integrity of the brake mechanisms mechanical linkages. The operation of the brake weight and broken link limit switches can be tested by manual operation while the conveyance is travelling at creep speed. This action must cause an emergency stop. The brake wear limit switch is activated by the brake weight when the brakes are applied. If the limit switch is not activated, an excessive brake wear condition has been detected and will be indicated at the operators panel. By marking the position of the switch and removing it, the operation of this device can be ascertained. The limit switch must be reinstalled correctly after this test has been completed. These tests can be used on hydraulic and disc brake systems where additional mechanical limit switches monitor the integrity of these braking systems.

3.4.7 Hoist drum rotational properties.

Most hoist control systems and protective devices use hoist drum measurements for control, protection and normal operating purposes. The measurement of hoist drum angular velocity, displacement and acceleration/deceleration can also be used to determine a measure of several parameters. The conveyance velocity and location are examples.

These measurements can be used to check the accuracy of existing sensors, which might be installed on the hoist drum. In addition, redundant checks on conveyance velocity and location can be made using these measurements.

Direct measurements can be made to determine these properties. To test the accuracy of existing sensors on the hoist drum, readings taken from the test equipment must be compared to those of existing instruments. However, the output of most of these devices is visual and is not stored in any form. Visual techniques can be used to compare two values. However this method is open to human error. Photographic techniques can be used to capture visual outputs at certain instances of time, allowing for a much easier and more accurate visual comparison. When devices with analog or digital outputs are encountered, software incorporated in the test device could undertake the accuracy checks.

3.4.8 The emergency stop tests.

CFR 30 (regulation 57.19-62) requires that " during emergency braking , the deceleration shall not exceed 16 feet per second per second." The emergency stop tests are conducted to determine compliance with this regulation, as well as providing other usefull information. Section 3.1.5 discusses the measurement of conveyance deceleration.

The elastic properties of the rope, and the differing load conditions experienced by the rope in relation to the conveyance location, require the emergency stop test to be conducted under four different conditions.

a. Conveyance lowered at its maximum regulated velocity, loaded to its maximum capacity, and the emergency stop is tested as close to maximum depth as possible.

b. Conveyance lowered at its maximum regulated velocity, with a zero load, and the emergency stop is tested as close to maximum depth as possible.

c. Conveyance hoisted from the lowest level at its maximum regulated velocity, loaded to its maximum capacity, and the emergency stop is tested as soon as maximum regulated velocity is attained.

d. Conveyance hoisted from the lowest level at its maximum regulated velocity, with a zero load, and the emergency stop is tested as soon as maximum regulated velocity is attained.

The emergency stop test has to be conducted for lowering as well as hoisting since braking is gravity assisted when the conveyance is moving upwards. The conveyance is tested fully loaded and unloaded since there is evidence that maximum deceleration rates can be encountered during emergency stops involving unloaded conveyances. (3)

Measurement of conveyance acceleration, deceleration, location, velocity, drive motor power, drive motor armature and rotor currents and voltages are to be taken during these tests. In addition the operator panel emergency stop button and the hoist brake pads will be monitored to determine exact time of triggering and brake pad movement respectively. These measurements are more fully described in section 3.1.8.

The procedure to be followed during the tests can be split into two groups: first, an emergency stop with the conveyance being lowered; second, an emergency stop with the conveyance being hoisted. In the first group, all tests will be initiated with the conveyance being lowered from the collar. The hoist operator will push an emergency stop button when the conveyance is travelling at maximum regulated velocity and has reached the three quarter depth point in the shaft. This will give the hoist operator enough time to stop the hoist manually if the emergency stop button malfunctions. All tests falling in the second group will initiate the test from the lowest landing in the shaft. The conveyance will be accelerated to maximum regulated velocity as quickly as possible. The hoist operator will then push the emergency stop button when this velocity is attained. The emergency stop button to be used in these tests is the button legally required to be within reach of the hoist operator. If this button is not operational, these tests will not be conducted. It is important that the emergency stop tests not be conducted at too close of time intervals. This is because repeated fast braking in a small time interval, can cause overheating of brakes and linings which could result in brake fade and eventually total brake failure (8).

A group of tests has been described to determine conveyance deceleration for several different emergency stop conditions. An assessment of compliance with CFR-30 (regulation 57.19-62) can be made using these test measurements. Time interval studies from one inspection to the next, of emergency stopping distances measured under the same emergency stop conditions, could be used to detect the occurence of brake fade or the slow deterioration of brake performance over time. On each test the electrical actions performed by the hoist during the emergency stop could be examined for component failure within the emergency stop circuit. These control system actions should be the same on each test. The emergency brake response times could also be incorporated into a time interval study. This study could reveal possible deterioration in the hoist system brake response time, indicating the presence of a possible component malfunction.

3.4.9 Standard controlled stop tests.

CFR 30 (regulation 57.19-62) requires that ; "maximum normal operating acceleration and deceleration shall not exceed 6 feet per second per second." The standard controlled stop tests are conducted to assess compliance with this regulation, as well as providing other useful information. Section 3.1.5 indicates the measurement of conveyance acceleration and deceleration.

Measurements of conveyance acceleration, deceleration, location, velocity, drive motor power, drive motor currents and voltages are to be taken during these tests.

The elastic properties of the rope and the increasing load experienced by the rope with depth, necessitates the standard controlled stop test being conducted under several different conditions. These are :

a. Conveyance lowered at 50% of its maximum regulated velocity, loaded at its maximum rated capacity, and will be stopped as close to shaft bottom as possible.

b. Conveyance lowered at its maximum regulated velocity, loaded at its maximum rated capacity, and will be stopped as close to the shaft bottom as possible.

c. Conveyance hoisted at its maximum regulated velocity, loaded at its maximum rated capacity, and will be stopped as soon as test velocity is attained.

A standard controlled stop is that stop used in every day normal operation of the hoist. This braking could by supplied by mechanical braking, regenerative braking, dynamic braking, motor plugging, or any combination of these methods.

For tests a. and b. above, the tests will be initiated at the collar. The hoist operator will then stop the conveyance at the lowest landing as required during normal operation. In test c. the conveyance will be accelerated from the lowest landing, and a normal operating stop performed when the test velocity is attained. Automatic hoists should be operated in the automatic mode for these tests.

These tests can be used to assess compliance with CFR 30 (regulation 57.19-62). Measurement of conveyance velocity and location can be used to construct a velocity location profile. This gives stopping distances, exact location of stop, and conveyance velocity when the stop was initiated.

4. INSTRUMENTATION

Advantages and disadvantages.

Most of the instrumentation recommended for the measurement of hoist performance parameters have been extensively used in the past for their application and thus do not need any further discussion. However, there is a group of parameters where each could have been measured using any of several different devices. This section will address these parameters: conveyance speed and location, hoisting mechanism shaft rotational properties, conveyance acceleration, rope tension and mechanical shaft torque. The advantages and disadvantages of using different devices for their measurement will be listed.

4.1 Conveyance speed and location.

Sensors that could be used for the direct measurement of conveyance position and velocity, are the following:

a. Radar transciever.
b. Laser transciever.
c. Ultrasonic transciever.
d. Microwave transciever.
e. Infrared transciever.
f. Conveyance mounted "guide-rider" wheel with a revolution counter for determining conveyance displacement and a tacho-generator for determining instantaneous conveyance velocity.

Items a thru e require that the transciever be placed in the headframe directly above the conveyance and a target installed on top of the conveyance, or the transceiver be placed in the sump and a target installed on the bottom of the conveyance. The often large amount of falling debris found in mine shafts, makes the installation of a transciever in the sump undesirable.

The advantage of using a transciever is:

a. They do not require transmission of data from the conveyance.

The disadvantages are:

a. It could be extremely difficult to install and align the transciever and its target.

b. It would be extremely difficult to keep the target and transciever aligned.

c. Interference occurs when operating the instrument in a confined space such as a shaft, causing errors in measurement or no measurement. The interference is due to the harsh conditions encountered in the shaft environment, i.e. high humidity, large temperature ranges, high particle quantity in the air, large amount of air movement, turbulence, etc.

d. The possibilty of extraneous targets being present in the shaft or on the conveyance itself.

The advantages of using the mechanical "guide-rider" odometer and tachometer are:

a. It is easily calibrated.

b. It is robust and portable.

c. It is commercially available at present.

The disadvantages are:

a. Inaccuracy due to slippage that might occur between the "guide-rider" and the guide. However high friction material on the wheel will reduce slippage.

b. Unwanted material on the guide could cause inaccuracies.

The "guide-rider" odometer and tachometer were chosen as the best instruments to use for this application. The odometer and tachometer are easy to install,operate and calibrate, as well as requiring no transmission of data to the surface from the conveyance. All data collected from these instruments will be stored on board the conveyance. These devices are relatively inexpensive and commercially available.

4.2 Hoist drum and drive motor shaft rotational properties.

Sensors and transducers that could be used to measure hoist drum and drive motor shaft rotational properties, i.e., angular velocity, displacement and acceleration, are the following:

a. A wheel tachometer that would ride on the hoist drum shaft, or any other known smooth diameter.

b. A gear with teeth and proximity sensor type of tachometer. A toothed gear located on the drum or directly coupled to the drum is used to generate a pulse when a tooth passes the stationary proximity sensor.

c. A photo tachometer. An adhesive strap striped evenly with reflective and non reflective material is placed on the drum shaft. A suitable transciever is then aimed at the strap. The rotation of the shaft will cause pulses to be received by the transciever. A reference reflector will indicate the occurence of a full revolution.

The advantages of using the wheel tachometer are:

a. It is easy to install in most cases.

b. It is portable and robust.

c. It is easily calibrated.

d. It is commercialy available at present.

e. Will indicate the direction of motion.

The disadvantages are:

a. Slippage between the wheel and shaft could cause inaccuracies to occur.

b. Physical contact with the shaft is required.

The advantage of using the "gear tooth and switch tachometer" is:

a. Will indicate the direction of motion.

The disadvantages are:

a. Requires the presence of a toothed gear of known dimension.

b. It is difficult to calibrate, as the exact dimension of the teeth, the exact tooth spacing and the number of teeth must be known.

c. Damaged teeth could cause inaccuracies to occur.

d. The exact position of the proximity sensor is important and its movement can cause inaccuracies to occur.

The advantage to using the photo tachometer are:

a. It is easy to install.

b. It is portable and robust.

c. It is easily calibrated.

d. It is commercialy available at present.

The disadvantages are:

a. Requires a series of stripped straps for each shaft diameter encountered.

b. Does not indicate the direction of motion.

The photo tachometer was chosen as the best instrument to use for this application. It is very easy to install, operate and calibrate, as well as being commercially available and inexpensive.

4.3 Conveyance acceleration.

Sensors and transucers that could be used for direct measurement of conveyance acceleration are the following:

a. Tri-axis accelerometer mounted on the conveyance.
b. Tachometer wheel that rides on the conveyance guides.
c. Radar transciever.
d. Laser transciever.
e. Ultrasonic transciever.
f. Microwave transciever.
g. Infrared transciever.

The advantages of using the Tri-axis accelerometer are:

a. It is a proven instrument for this application.
b. Gives three perpendicular axes for acceleration measurement.
c. It is easy to install.
d. It will report dynamic accelerations.
e. It is commercialy available at present.
f. It is portable and robust.

The advantages of using the wheel tachometer are:

a. It is easy to install in most cases.
b. It is portable and robust.
c. It is easily calibrated.
d. It is commercialy available at present.
e. Will indicate the direction of motion.

The disadvantages are:

a. Slippage between the wheel and shaft could cause inaccuracies to occur. However, high friction material on the wheel will reduce slippage.
b. Unwanted material on the guides could cause inaccuracies of measurement.
c. Physical contact with the shaft is required.

The advantages and disadvantages of using transcievers are listed in section 3.5.1. The Tri-axis Accelerometer was chosen as the best instrument to use for this application. This instrument is widely used for this application, and has been proven.

4.4 Mechanical shaft torque.

The following shaft torque measurement methods were studied :

a. Use of strain gauges.

b. Differential transformer method.

c. Variable permiability method.

d. Pulse method.

e. Optical methods.

The signals from these devices would be transmitted from the rotating shaft using a transmitting collar attached to the shaft and a stationary antenna place around the collar. These measurement methods are well known and documented (12).

The advantage of using any one of methods is :

a. They are the available methods.

The disadvantages to using any one of the methods a. - e. are :

a. Several physical properties of the shaft must be known. That is, modulus of elasticity, etc.

b. All the methods require permanent application of the transducer to the shaft, and in some cases bolt holes would have to be drilled in the shaft.

c. All these methods require specially skilled personnel for installation.

d. They are difficult to calibrate and time consuming to install.

None of these methods are acceptable for the determination of mechanical shaft torque. They do not fit the ease and time of installation criteria for the inspection procedure; therefore, mechanical shaft torque will not be measured.

5. DEFINITIVE DESIGN OF THE AUTOMATED TEST SYSTEM.

To accomplish the recommended design considerations for an automated inspection and testing system, the operational requirements of the system must be determined. The capabilities of the mine hoist electrical inspection system should be the following :

a. Perform real time measurements.

b. Perform calculations on these measurements.

c. Make recordings of pertinent data.

d. Generate hard copy data.

e. Have the capability of mass storage capacity.

f. Be interactive with the user.

g. Have the capability of accepting analog and digital data.

h. Have the capability of performing signal conditioning.

i. Be menu driven for user-friendly operation.

j. Set separate sampling rates for each input.

k. Have the ability to perform sensor and transducer operation verification.

l. Contain a range of built-in data analysis software.

m. Be reasonably portable.

n. Have a large number of input data channel capability.

o. Have graphics capabilities.

The system configuration must be adaptable to the location and conditions under which the inspection is taking place. If the hoist is situated on the surface and the hoist house is easily accessable then the fully configured system can be used. When the hoist is located under ground or is not easily accessible a smaller more portable system will be used. After testing the smaller configured system will interface with the larger system for complete data analysis. The requirements of these two systems are different and will be dealt with separately.

5.1 The fully configured system.

This system will have the capability of implementing all the measurements and data analysis required for a complete mine hoist electrical system inspection. The organization and management of the testing will be undertaken by this totaly integrated system. Signal conditioning modules, computer cards, keyboard, display, mass storage, printer, etc will all be contained in one unit.

The full system configuration will be as shown in figure 5.1. The base memory requirement is impossible to ascertain without the developement of all the software. One $5\,{}^{1}/_{4}$-in. floppy disc and a hard disk drives will be incorporated into the system. Floppy discs will be used for digital data storage as well as storage of computer programs and test plans. Analog data storage will on magnetic tape. Reports and plots will be generated at the test location using a small built-in thermal printer. More extensive reporting will be created using a larger printer. These printers will create all the hard copy data required. A 9 in. CRT and hidden membrane keypad will be incorporated into the system itself. A keyboard and color monitor will be used in remote situations, where the they can be located up to 100 ft from the system. Communications capabilities will be available with the system in the form of IEEE-488 and RS-232 communications ports.

5.2 Data acquisistion system.

The Data Acquisistion system front end is formed around the data collection system bus which is linked to the computer, See figure 5.2. The data collection system will accept analog and digital signals; A/D converters and signal conditioning should be incorporated into the

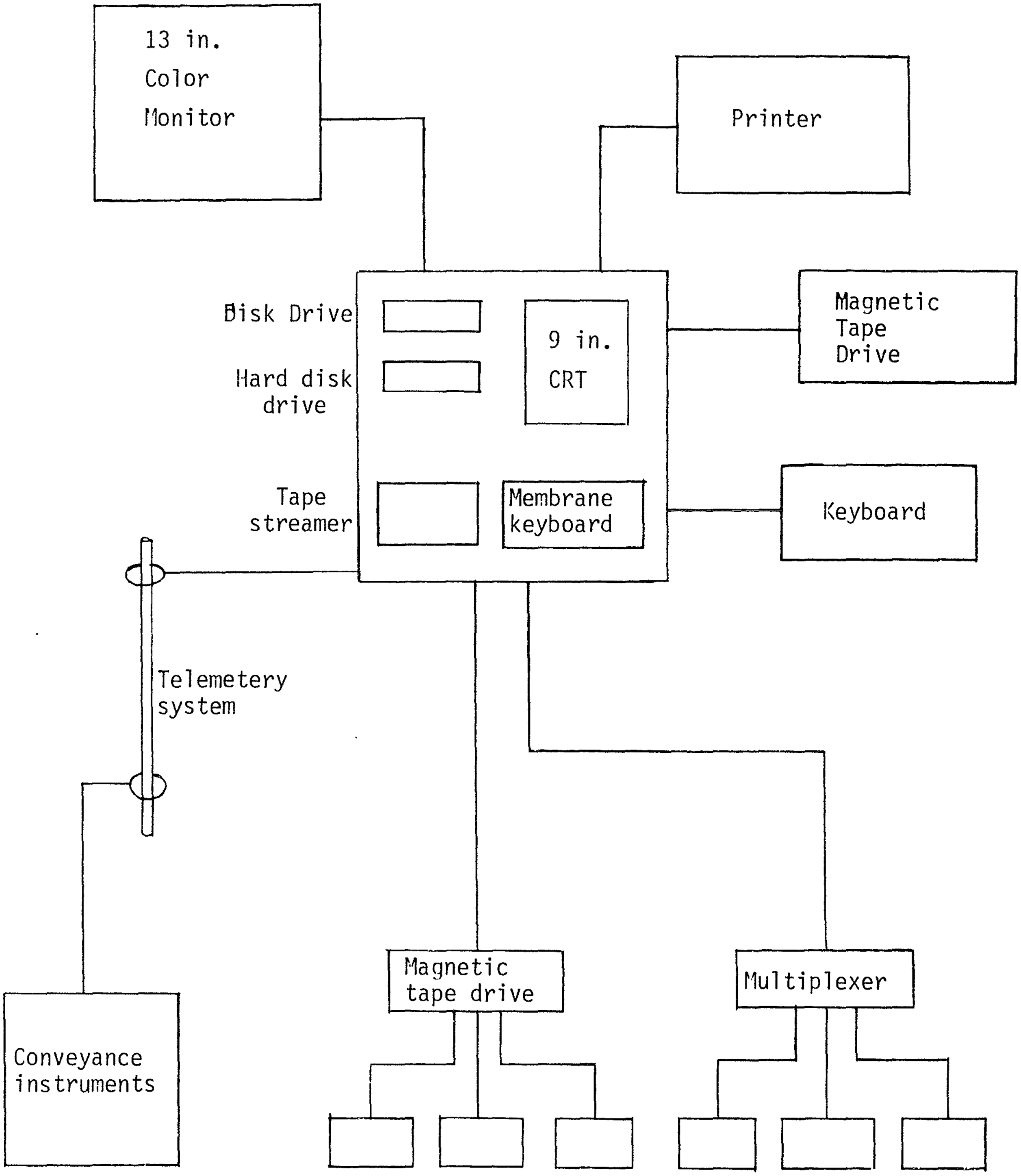

Figure 5.1 - Fully configured system.

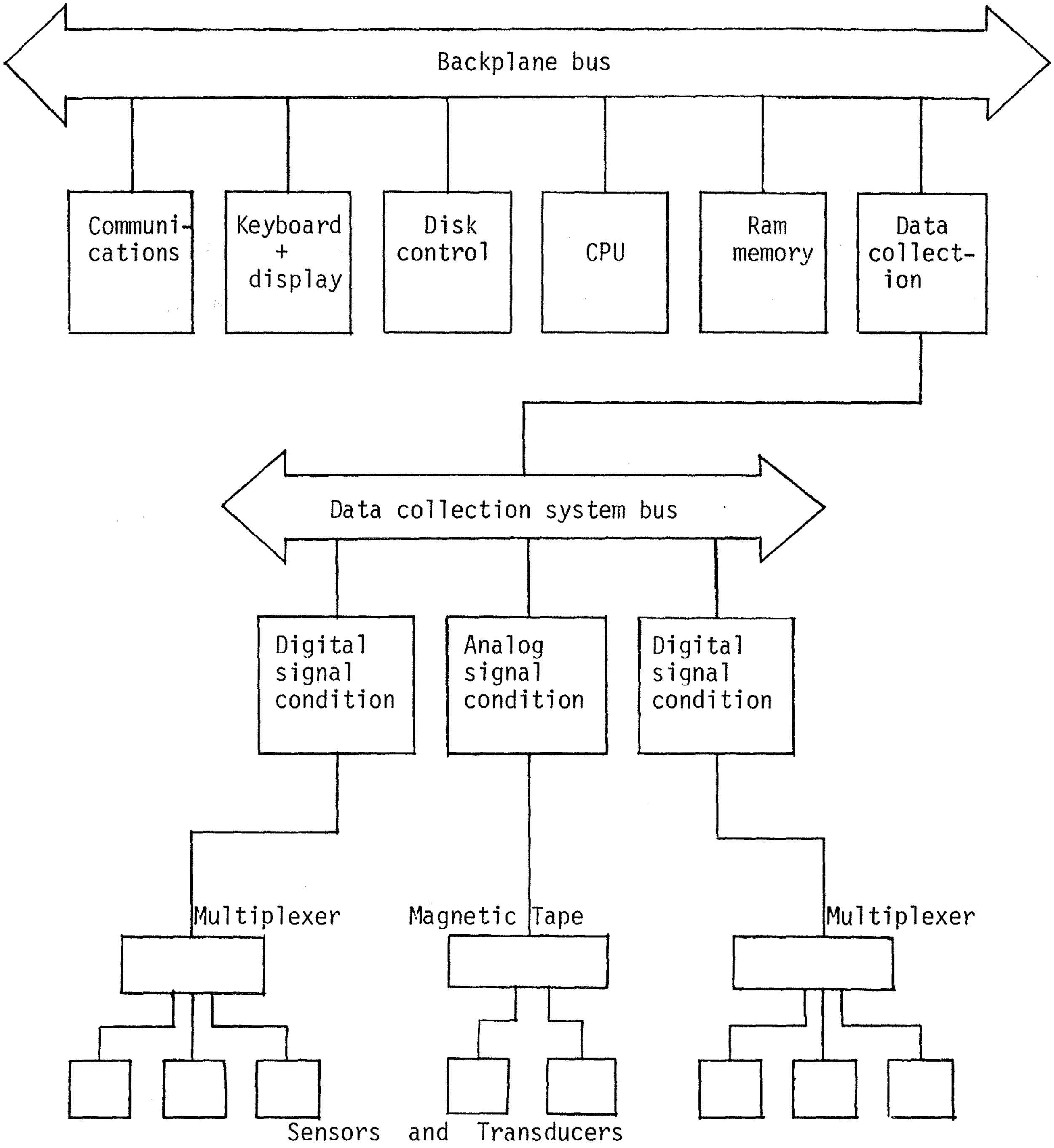

Figure 5.2 - Basic system.

system. Typicaly, the sampling rate can be 5 times the band width of the analog signal input. To prevent having to wire sensors directly to the cards, the signal lines will be connected to termination blocks which can easily be plugged onto the cards.

5.3 Testing.

The design of testing considerations requires a flexibility in the sampling rates dependent on the type of testing being conducted. Static testing in the mine hoist electrical inspection system involves comparitively slow sampling rates. Dynamic testing may require sampling rates up to 10000 samples/sec/channel, and transient testing sampling rates will be still higher. A limited degree of transient testing will be conducted, and thus very high sampling rate capabilities will only be required in special situations. Although the sampling rates required can only be determined in a final design phase, these measurements should fall in the following test sampling rates (samples/sec/channel) :

10 - 200 : Drive motor currents, voltages, frequencies, and powers.

200 - 500 : Monitoring of switches and protective devices. All devices measuring the rotational properties of the hoist drum and hoist drive motors. Measurements taken from the rope tension measuring device.

500 - 1000 : All conveyance mounted devices. That is, the tri-axis accelerometer package, the "guide-rider" wheel tachometers and odometers.

The total inputs into this proposed system at one time will be on the order of 170. A capability of 250 input channels should be sufficient.

5.4 Operating system.

An industry standard operating system should be used for both program developement and the end user. A multitasking, multiprocessor operating system that specializes in real time applications should be used. The software should boot at which time control is assumed by the "test management" software, which is layered above the operating system. The "test management" software is a collection of menu-driven routines that provide help to set up and run tests, configure the display, or perform off-line analysis. The user will enter the operating system utilities and compilers from the main menu when program developement is required.

5.5 Test plans.

To make the developement of "test plans" more user-friendly, a menu driven design kit will be used. This consists of a sequence of commands and parameters which configure the measurement strategy. Once created, all test plans will be stored in a disk file and could be recalled, modified or executed at any time. Separate utilities will be used to verify basic aspects of the plan, such as signal connections and limit checks, and perform tests to take a "quick look" at preprocessed data. A test plan or series of test plans will be initiated with a few keystrokes. These test plans will be run during the inspection tests, thus guaranteeing measurement accuracy, reliability, and repeatability.

Appendix 2 provides the flowcharts to guide the mine inspector or operator for installing the test instrumentation prior to data collection for inspection tests. Appendix 3 provides the instructional flowcharts to guide the mine inspector or operator for conducting the inspection tests.

5.6 Analyzing results.

The system will be equiped with an array of data analysis software languages, such as C, Pascal, and Fortran. Data management packages will be used for basic math functions such as add, subtract, multiply, divide, sine, cosine, cumulative summation, etc. Time domain software packages will provide the capability for unit conversions, averaging, statistics, auto and cross correlation, digital filtering, curve fitting, numerical differentiation and integration, etc. Frequency domain packages will do Fast Fourier Transform, rms spectrum, power spectral density, cross power spectrum, coherence, transfer function, etc.

5.7 Conveyance system.

The instrumentation located on the conveyance is isolated from the rest of the system, see figure 5.3. To avoid having to transmit data from the conveyance to the surface, all data will be recorded on the conveyance using magnetic tape. The accelerometers, "guide-rider" wheel tachometers and odometers output will be analog. 15 analog signals should be recorded. Telemetry using the hoist wire rope will be used to transmit a time reference signal to the conveyance. After the tests have been completed the main system will convert the data on the magnetic tape to digital data. The digitized data will then be stored on diskette for analysis on the site.

The use of telemetry for the required signal transmissions could be undesirable if not impossible in the case of slope hoists. When the conveyance remote there is a high probability that the wire hoist rope will be in contact with the earth. All signal connection and instrument operation verification will therefore be executed by the instrumentation

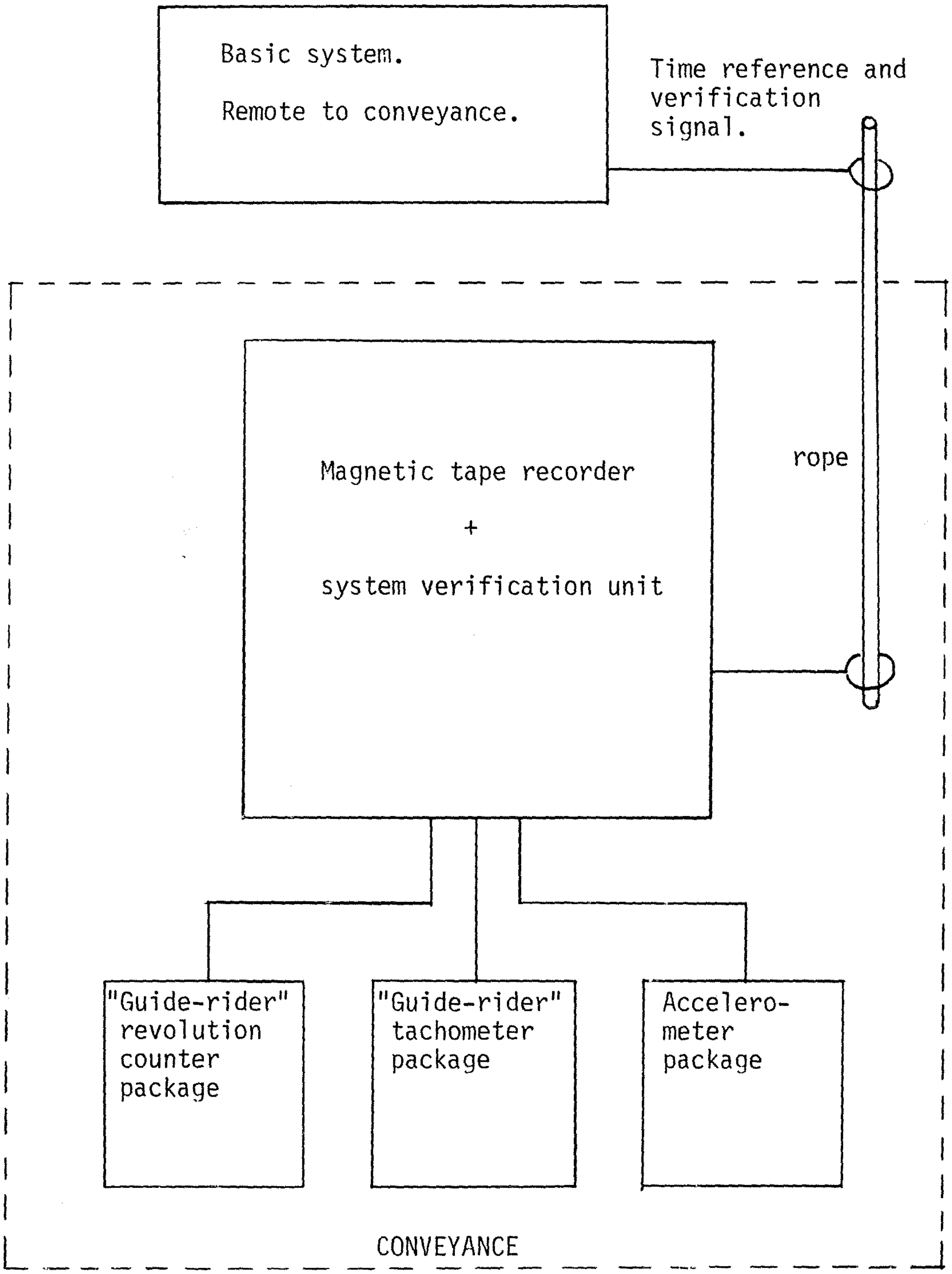

Figure 5.3 - Conveyance configuration.

on the conveyance. The time reference could be transmitted to the conveyance using the signal wires located in the slope. This signal is not required during the test, only before the test can be conducted. This transmission is required while the conveyance is stationary and not during its movement.

5.8 The limited configuration sub-system.

This smaller sub-system will have far less capabilities than the main system. It will be portable so that it can be used in locations that are not easily accessable. The system must be rugged to endure harsh underground conditions.

The sub-system configuration will be that shown in figure 5.4. Limited computing capabilities are required, as no data processing will be performed by the sub-system. Only very limited analysis of certain data will be performed by the sub-system. The hardware will consist of a 9 in. CRT, a hidden membrane keyboard, $5\,^1/_4$ disk drives, a hard disk, and a small built-in thermal printer. The sub-system will have the same capabilities as the main system for data acquisition, signal conditioning, static and dynamic testing, and running test plans. However, the sub-system will only perform limited short-run tests on the preprocessed data to verify basic aspects of the test, such as signal connections and limit checks. The conveyance equipment will be the same as that for the fully configured system.

5.9 Basic Cost Estimate.

The basic cost estimate indicated that the cost to build this proposed Mine Hoist Electrical Testing System, would be in the order of $300,000.00 to 350,000.00. The costs can be broken up into the following components :

a. Fully configured test system - $50,000.00

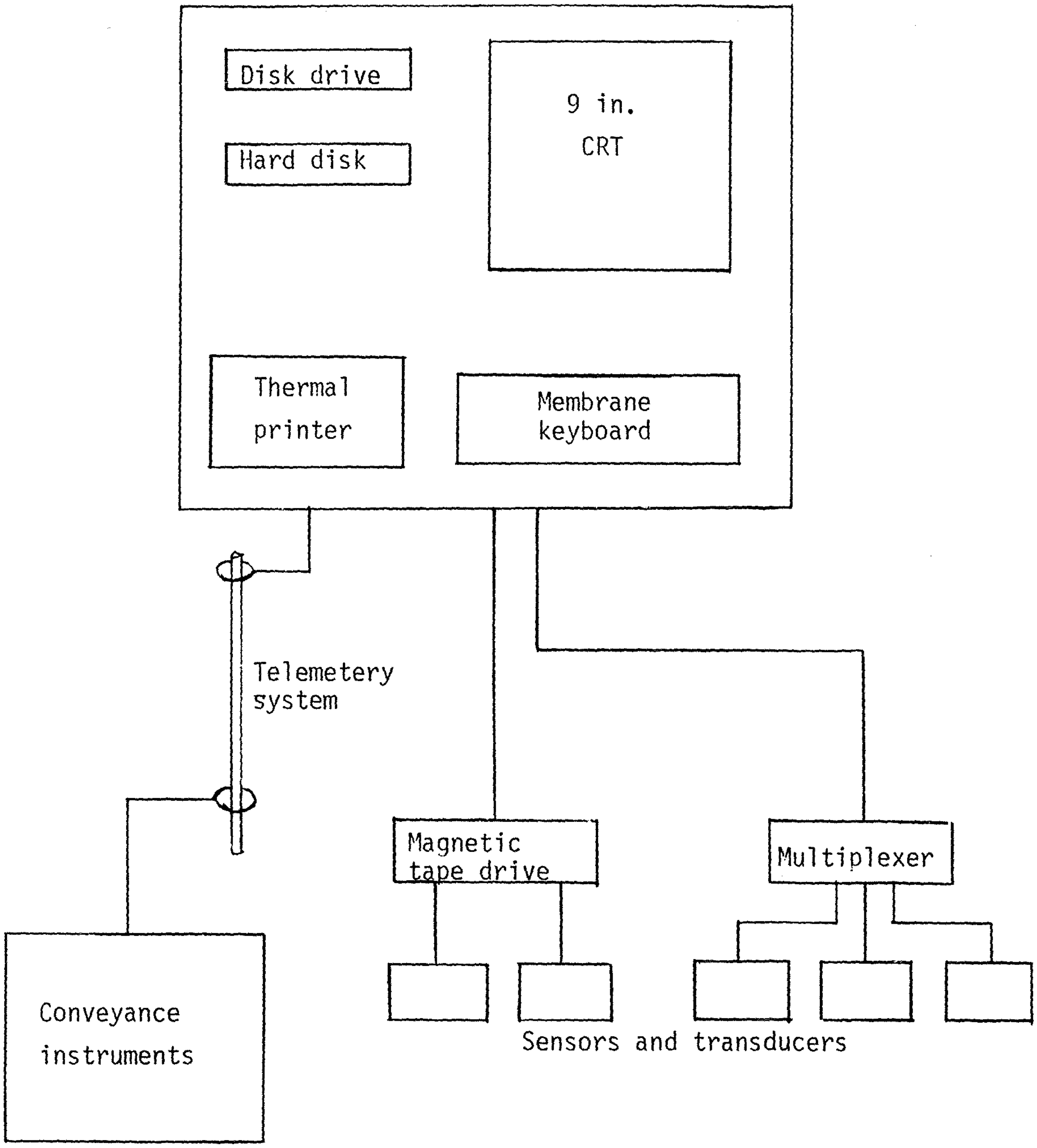

Figure 5.4 - Sub-system configuration.

b. Sub-system - $40,000.00

c. Sensors and transducers - $210,000.00

Total cost of system is $300,000. These figures do not include spare equipment needed in the event of instrument malfunctions.

6. CONCLUSIONS AND RECOMMENDATIONS.

The investigation has yielded recommended design considerations of a system that performs real time measurements, calculations, and recordings of pertinent hoist performance data. The system has hard copy and mass data storage capabilities. A determination of how and what parameters are to be collected from a hoist system was made. These parameters include current, voltage, and speed. Calculations on various data to determine acceleration, deceleration, distance traveled, peak current, peak voltage, and average voltage will be made. The system will determine power during acceleration and deceleration, torque requirements of various loads, distance traveled during emergency stop, deceleration rate during emergency stop, regulator response time, current limit settings, rope stretch and brake condition. A measure of motor shaft torque will also be assessed. Methods to assure that current, voltage, and speed signals within the hoist system are within tolerances were investigated.

Section 2.5 showed a list of values addressed in the report. This list has been split into three groups showing the author's assessment to insure the integrity of the mine hoist electrical system. The following rationale defines the groups:

A: Critical to the Mine Hoist Electrical System.

These variables are critical in making a reasonable assessment of the operational status of the mine hoist electrical system. This group will give the most useful information for the number of measurements taken.

Current.

Voltage.

Speed.

Acceleration.

Deceleration.

Power during acceleration.

Power during deceleration.

Motor shaft torque.

Regulator response time.

Grounded and grounding system condition.

Values during normal and abnormal (or emergency) conditions.

Emergency stop buttons.

Overtravel backout switch.

Overtravel protective devices.

Overspeed protective devices.

Hoist feeder power loss protection.

Hoist control power loss protection.

Hoist DC drive motor field loss protection.

Time interval related studies, i.e., comparison of results from one inspection ot the next.

B: Secondary, but important to the mine hoist electrical system.

These do not exist in many hoist configurations, and can often be obtained through the determination of variables in group A.

Distance traveled.

Peak current.

Average current.

Peak voltage.

Torque requirement for various loads.

Distance traveled during an emergency stop.

Deceleration rate during an emergency stop.

Current limit settings.

Elapsed time during acceleration and deceleration.

Clutch to brake interlock.

Mechanical brake testing and setting.

C: Least important to the mine hoist electrical system.

These are by-and-large non-electrical or related to non-electrical values. They could provide useful information to the operator about the hoist.

Rope stretch.

Brake condition during repeated stops.

Values at the drum. (where applicable)

Values at the cage, bucket, skip where applicable.

Velocity (speed) of various components during varying conditions.

A group of tests to ascertain the integrity of a hoisting system were determined. In addition, a user-friendly instruction set to guide an inspector through these test procedures were determined. These instruct personnel how to install the test equipment and conduct the tests. Other measuring methods that may be helpful in assessing the condition of the hoist were determined.

The testing system proposed in this report conforms to an automated method for gathering hoist control parameters and performing analyses. It will indicate the operational status of a hoist electrical system within the framework of the parameters collected. This study shows that the system is feasible.

If the proposed testing system were to be implemented, a reasonable supply of spare equipment should accompany the system. Harsh environments encountered at mines will cause some sensor, transducer and system malfunctions. Remote mine locations will necessitate a supply of spares. The size and cost of this supply was not included in the basic cost estimate. This is a topic for further research.

Detailed investigation into the hardware and software requirements of the indicated hoist electrical testing system be the next research work in the area. Detailed equipment installation and test procedures would then have to developed and implemented, followed by the training of personnel in the use of the system. These areas were well beyond the scope of this study.

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10. U. S. Code of Federal Regulations. Title 30--Mineral Resources; Chapter 1--Mine Safety and Health Administration; Part 57--Health and Safety Standards - Metal and Non-metal Underground Mines.

APPENDIX 1.

Rope tension.

There are several approaches that can be taken in attempting to measure the actual rope tension. The first is to place a load measuring device such as a load cell, in the rope or in one of the rope attachments. Another is to place load measuring devices in the shaft bearings of the sheave wheel(s). The component of that force in the direction of the shaft is the tension in the rope. These methods require transducers that are difficult and very time consuming to install, and once in place must be considered as permanent fixtures. The satisfaction of these methods is not known as they have only been applied in a few cases. These methods are unsatisfactory for use in the inspection procedure.

From the literature survey and information obtained from manufacturers, it became evident that a suitable transducer capable of measuring hoist rope tension, was not commercially available. A definitive design of a device that could measure rope tension was developed.

The device shown in figures 1 and 2 can be used to measure tension in the hoist rope. This measurement can be used to calculate torque at the hoist drum, leading to a measure of mechanical shaft torque at the hoist motor.

From figures 1 and 2, the letters represent the following :

A : A roller with a high friction surface.

B1: Hydraulic legs.

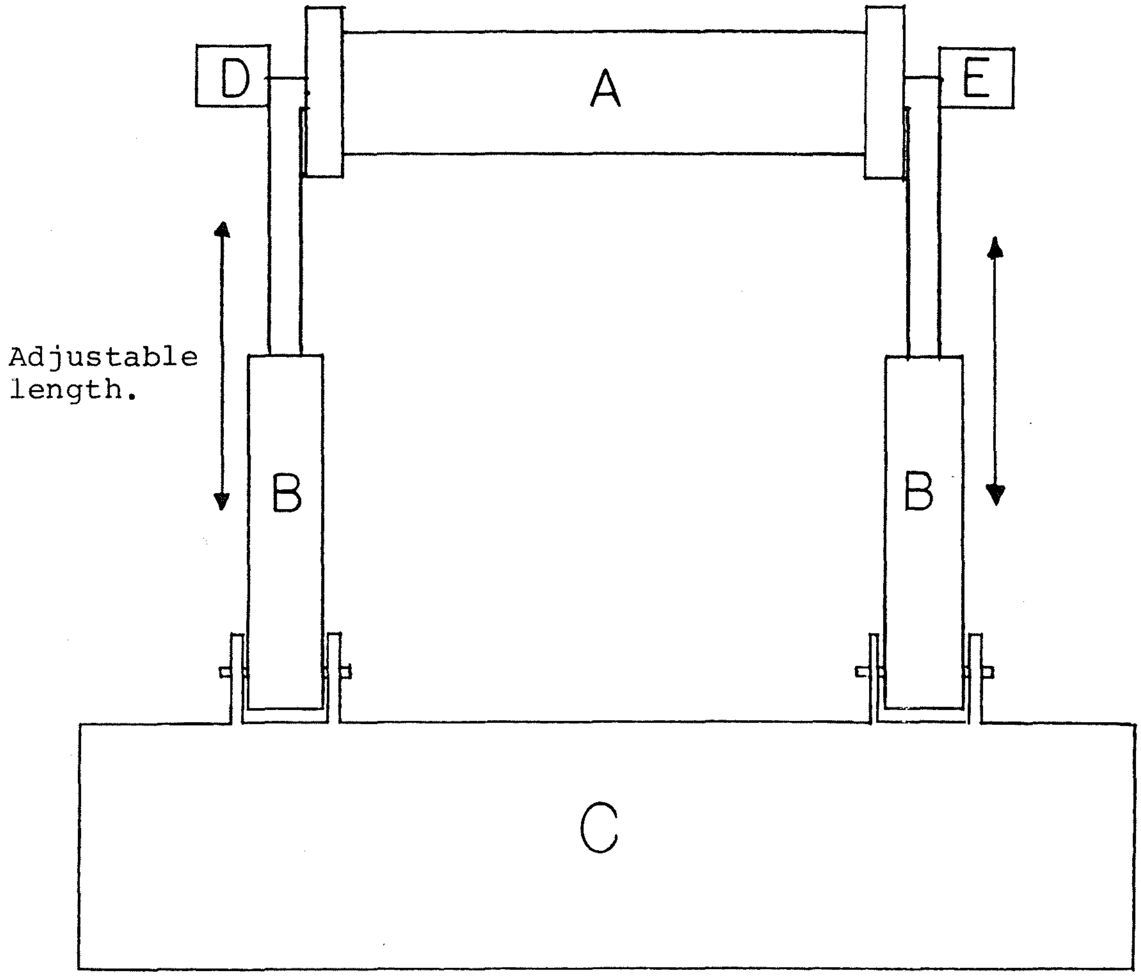


Figure 1 - Rope Tension Device. (Front view.)

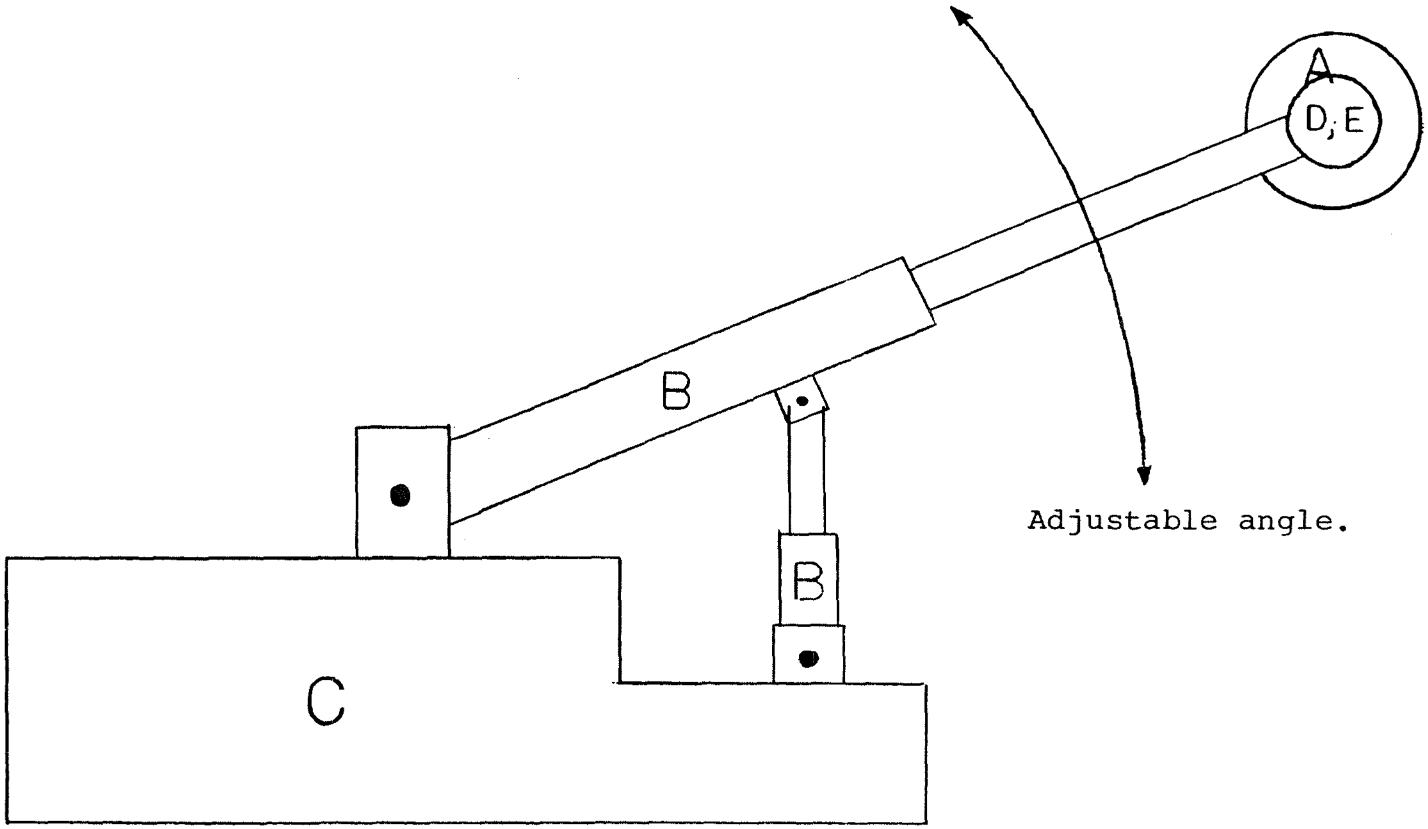


Figure 2 - Rope tension device. (Side view.)

B2: Hydraulic legs.

C : Mobile base.

D : Electric tachometer and odometer.

E : Angular accelerometer.

Instrumentation on the fixture :

1. The hydraulic legs B1 contain load cells to measure the force exerted by each leg, and devices to measure linear displacement of that leg.

2. The roller will be equipped with revolution counters (odometers) and longitudinal direction of movement sensors, as well as devices to measure rotational velocity of the roller (electric tachometer), and angular accelerometers to measure the rope acceleration and deceleration rates.

Placement of the fixture.

The test fixture could be used in the two positions as shown in figures 3 and 4 The placement used will depend on the physical layout of a particular hoist. Figure 4 placement must be used for tower mounted friction hoists. The fixture is placed such that the base is secure. The roller is then placed against the rope so the hydraulic legs are at right angles to the tangent as shown in figure 3 and 4. The rope is then displaced by extending the hydraulic legs.

Rope tension calculations.

The first case is where the rope tension device is located between the hoist drum and sheave wheel, as shown in figure 3. The total force F exerted on the rope by the hydraulic rams B1 and B2, and the displacement h of the rope from its normal position will be measured while the device is in use. The distances d_1 and d_2 will be measured

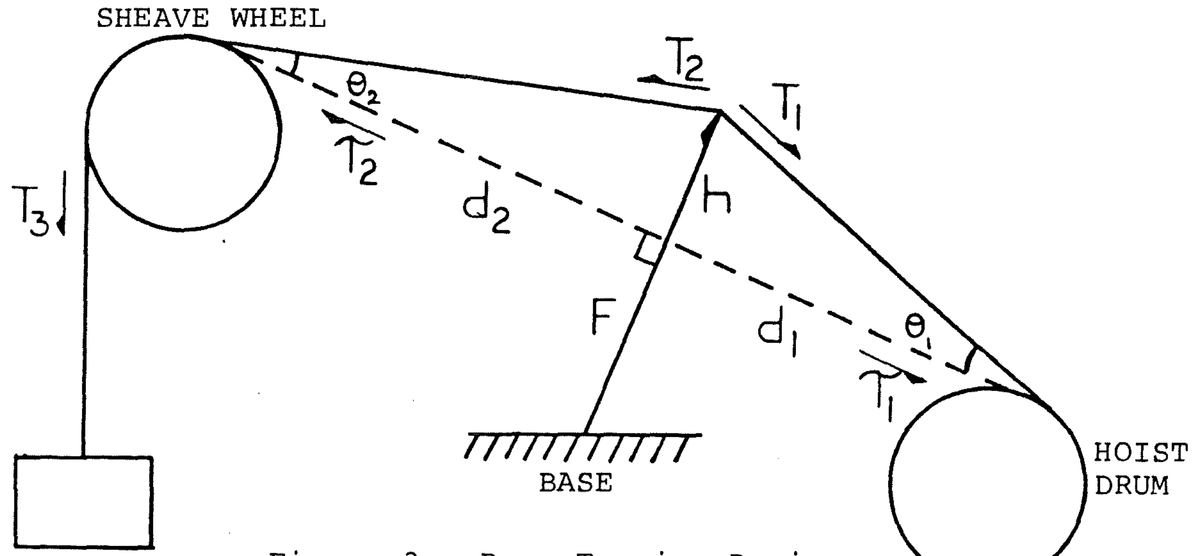


Figure 3 - Rope Tension Device
- Position 1.

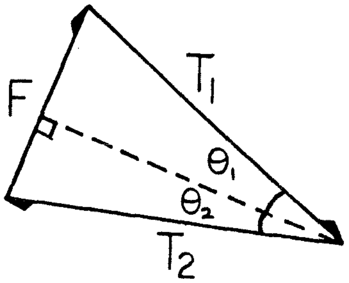


Figure 5 - Force Triangle

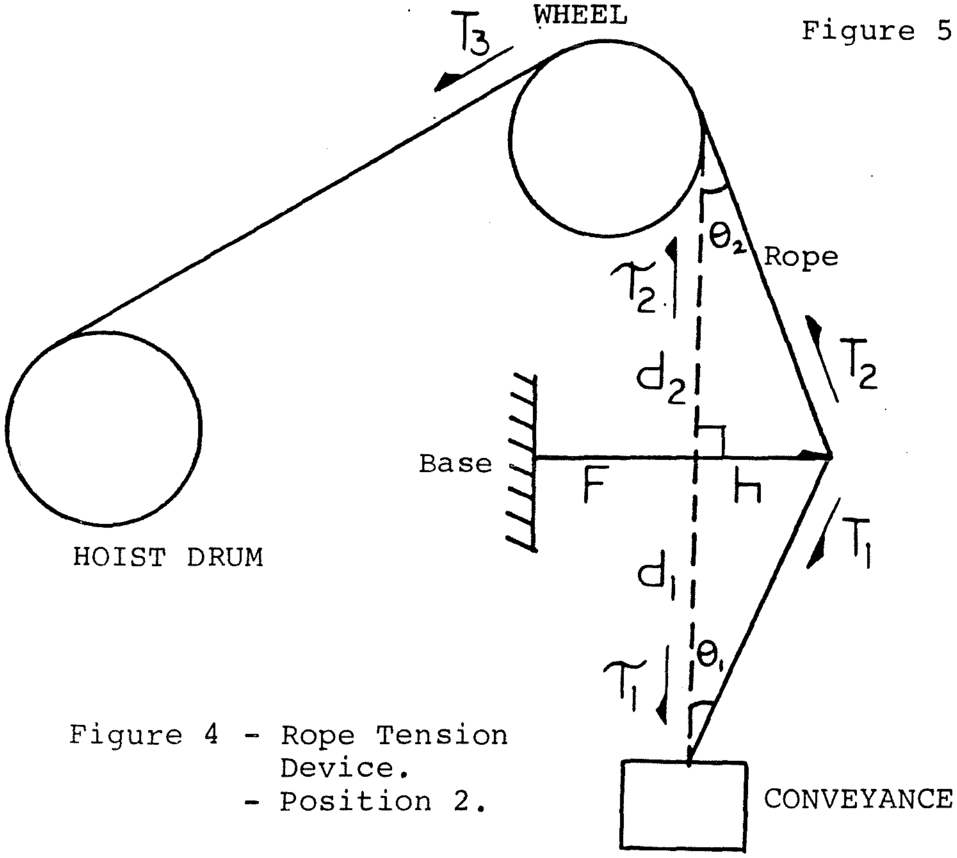


Figure 4 - Rope Tension Device.
- Position 2.

when the device is installed. The values of F, h, d_1, and d_2 will therefore be known constants.

T_t = Measured rope tension in the tth rope section.

$\mathcal{T}_t$ = Actual rope tension in the tth rope section.

d_t = Perpendicular distance between the hoist drum, sheave wheel or conveyance and the testing device.

h = Rope displacement due to testing device.

θ_t = Angle between original rope position and displaced rope position.

F = Force exerted on the rope by the testing device.

From the force triangle (figure 5) :

$$\frac{F}{\sin(\theta_1+\theta_2)} = \frac{T_1}{\sin(90-\theta_2)} = \frac{T_2}{\sin(90-\theta_1)}$$

Where : $\theta_1 = \tan^{-1}(h/d_1)$

$\theta_2 = \tan^{-1}(h/d_2)$

Therefore, $$T_2 = \frac{F\cos\theta_1}{\sin(\theta_1+\theta_2)}$$

and $$T_1 = \frac{F\cos\theta_2}{\sin(\theta_1+\theta_2)}$$

Therefore, the static and dynamic rope tension under normal operation can be represented by the following :

$$\mathcal{T}_1 = \mathcal{T}_2 = T_1\cos\theta_1 = T_2\cos\theta_2$$

The second case is when the rope tension device is located between the conveyance and the sheave wheel as shown in figure 4. The device will normally be located near the collar and closer to the sheave wheel than the conveyance. The force exerted on the rope F and the rope displacement h will be measured. The distance d_2 will be constant and will be measured when the device is installed. Distance d_1 will change as the conveyance changes location in the shaft, however it can be continuosly calculated from conveyance location. The values F, h, d_1, and d_2 will therefore be known.

From figure 3

$T3 = T2A\cos\theta2A$ + Inertia of sheave wheel + Friction between the rope and sheave wheel

APPENDIX 2.

Testing System Instrumentation Instruction Installation Flowcharts.

The instructional instrument installation flowcharts are designed to guide a mine inspector or operator through the procedure for installing the test instruments. The flowcharts do not specify detailed installation procedures, but give a method to determine what test equipment should be used, where it should be installed and the number required.

The flowcharts are designed to be followed in sequence. Once the requirements of the instrumentation flowcharts have been completed, the inspection tests are to be conducted in sequence (see appendix 3). This would be the most desirable inspection method. However, if the desire is to conduct an individual test , the test flowcharts contain a desciption of the test equipment required for that test. In addition, the instrumentation flowcharts list the tests for which each instrument is to be used. It is assumed that detailed installation manuals for the test equipment will be avaiable to enhance installation of the testing system.

Instrumentation installation flowcharts.

Flowchart name.	Chart
1. Installation flowchart base.	AA
2. Measurements of motor currents.	1
3. Installing DC "clamp-on" current sensors.	A1
4. Installing AC "clamp-on" current sensors - drive motor rotor circuit.	A4
5. Measurement of motor voltages.	5
6. Installing AC voltage sensors for line to ground voltage.	A2
7. Installing AC voltage sensors for line to line voltage.	A3
8. Measurement of DC motor field and armature voltages.	A10
9. Installing DC voltage sensors.	A15
10. Measurement of AC motor rotor frequency.	7
11. Installing Photo tachometers for drive motor shaft.	8
12. Installation of photo tachometers on motor shafts.	B1
13. Connection of existing hoist measurement devices to the testing device.	B2
14. Installation of accelerometers and "guide-rider" wheel packages on conveyance.	10
15. Measurement of hoist drum rotational properties.	30
16. Installing the rope tension device.	40
17. Installing rope tension measuring device at the collar.	40A
18. Installing rope tension measuring device at the hoist drum.	40B
19. Monitoring hoist feeder power.	50
20. Monitoring hoist control power.	60

CHART AA

Installation flowcharts.

Start at the top of the chart and move downwards after completion of each required instrument installation.

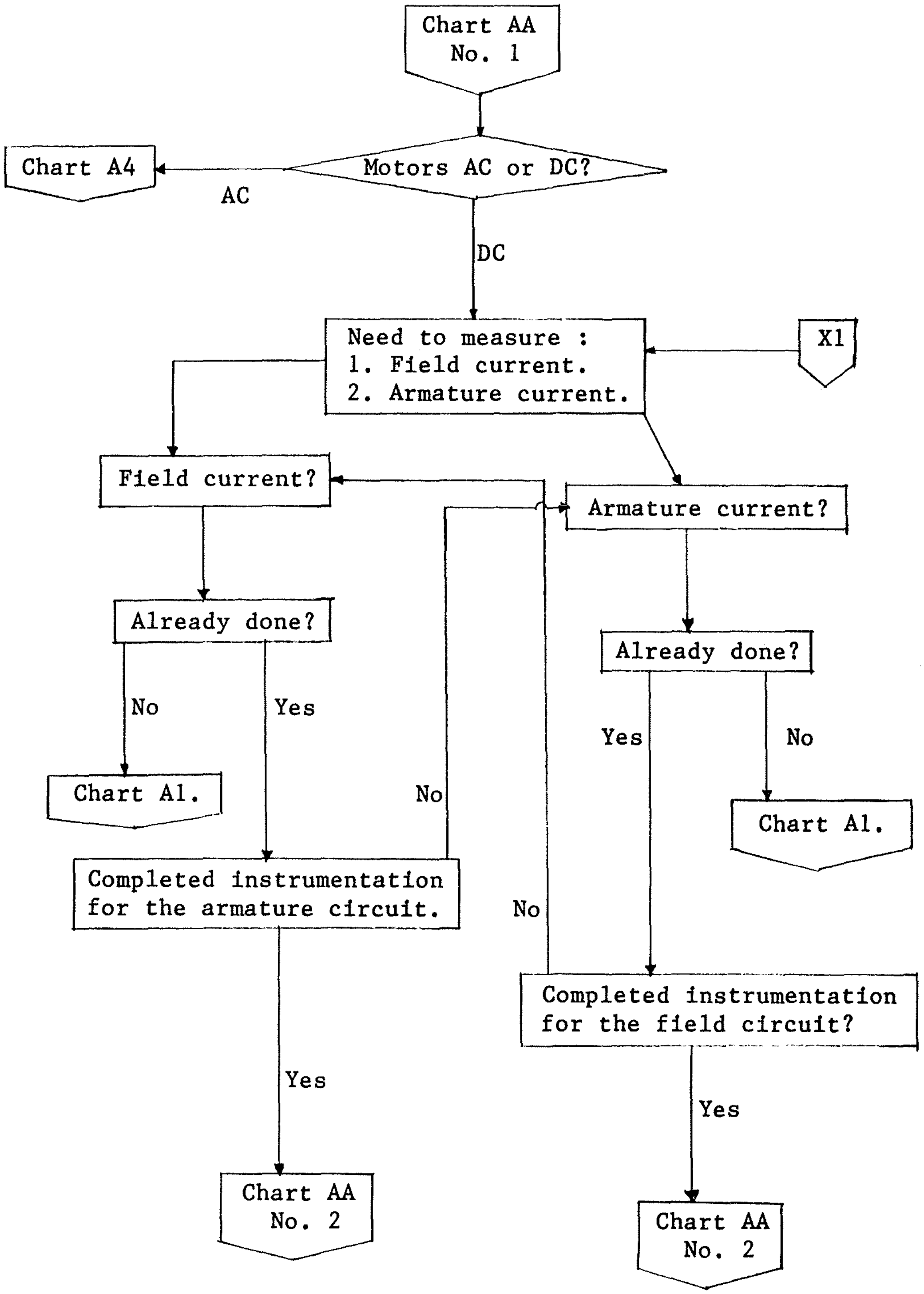
To measure or monitor.	Go to Chart No.
1. Measurement of motor currents.	1
2. Measurement of motor voltages.	5
3. Measurement of AC rotor frequency.	7
4. Measurement drive motor shaft rotational properties.	2
5. Measurement of conveyance speed, location and acceleration.	10
6. Measurement of hoist drunm rotational properties.	30
7. Installation of rope tension measuring device.	40
8. monitoring of hoist feeder power.	50
9. monitoring of hoist control power.	60

To measure or monitor.	Go to Chart No.
10. Monitoring the emergency stop button.	80
11. Monitoring the overtravel backout switch.	90
12. Monitoring the overtravel bypass switch.	100
13. Monitoring the overtravel and overspeed protective devices.	110
14. Installing the brake movement sensor.	120
15. Measurement of AC drive motor power.	130

INSTALLATION
CHART 1.

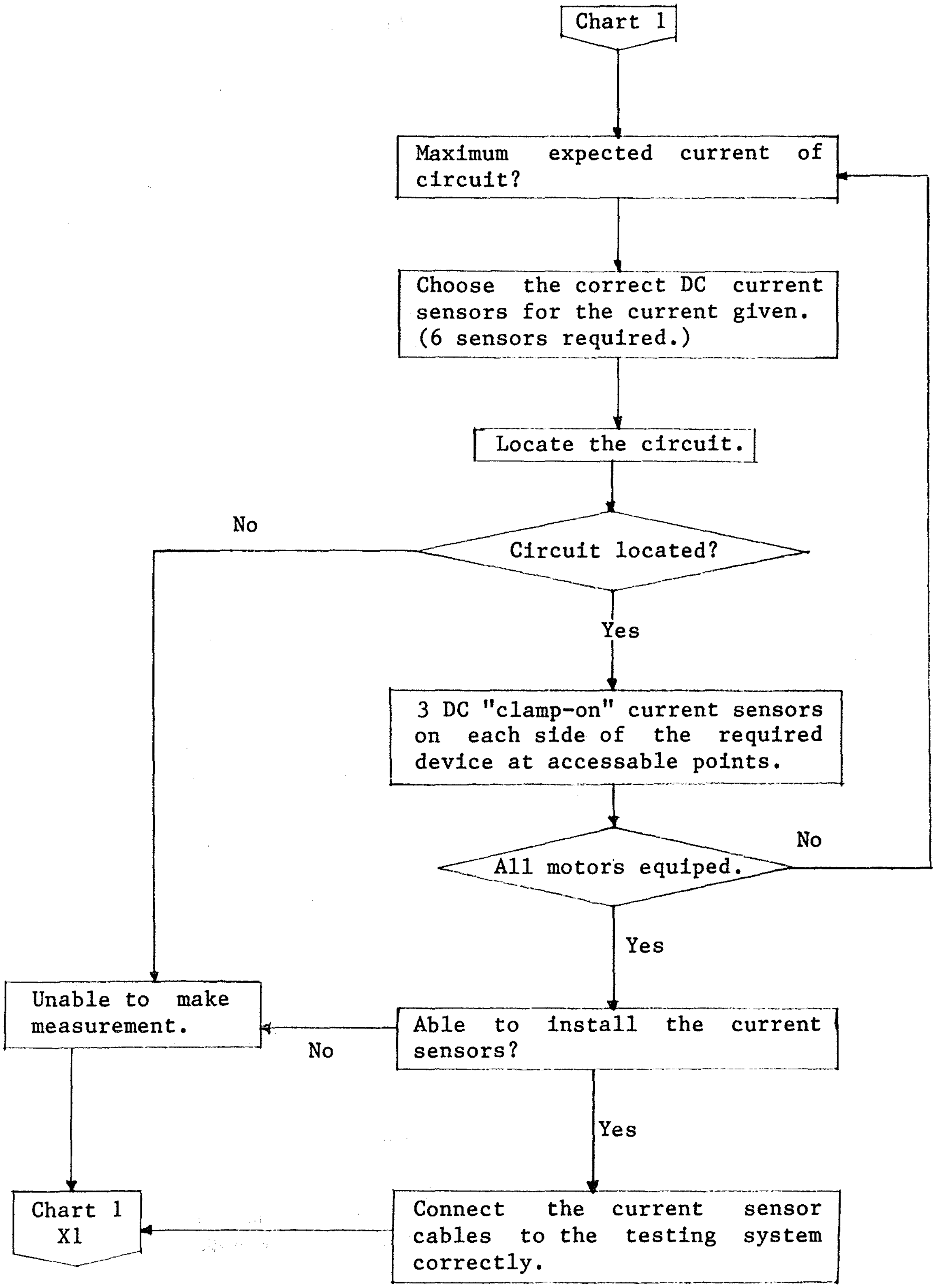
Measurement of motor currents.

For tests : Chart TT. Tests 1-14.



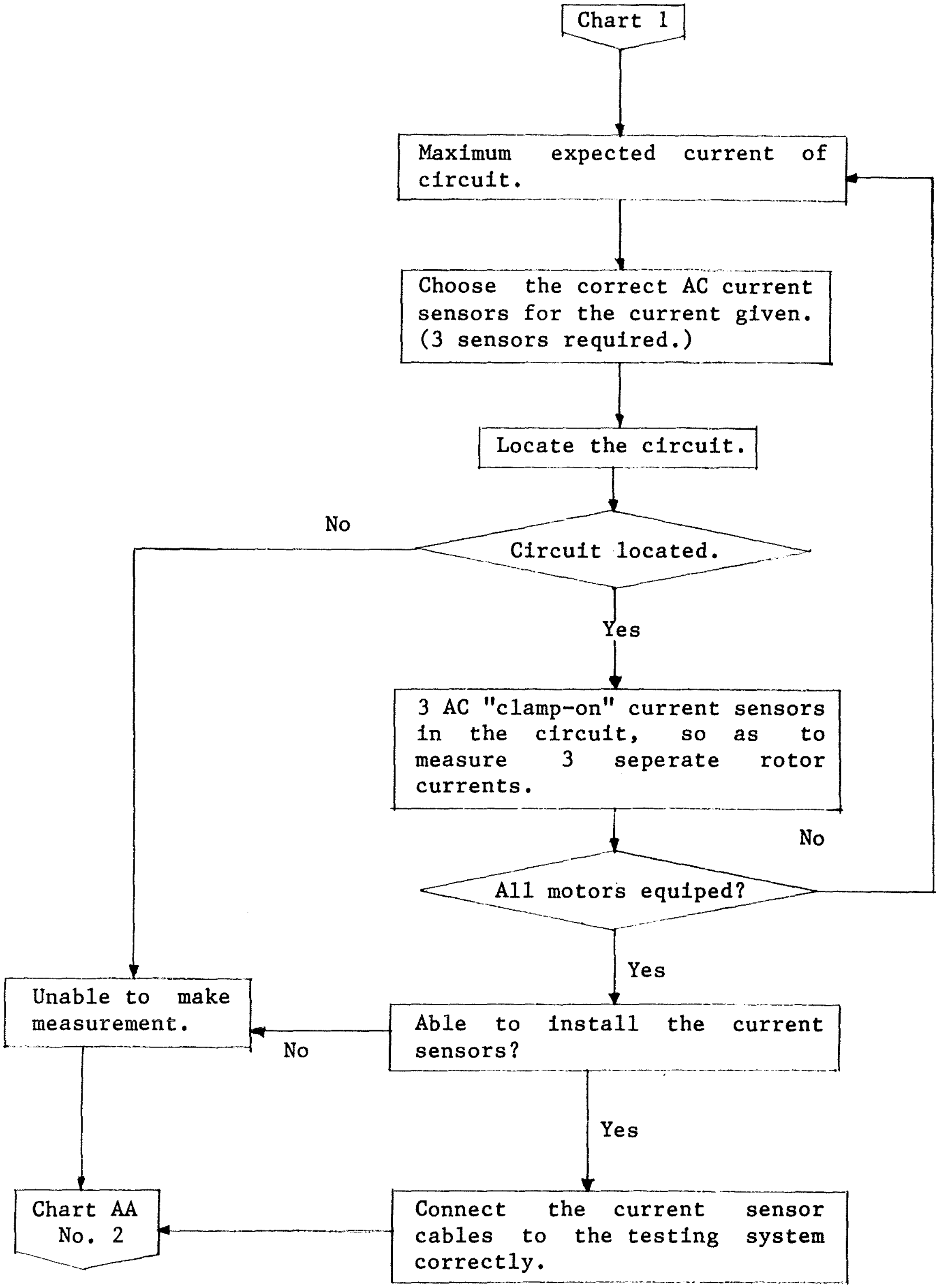
INSTALLATION
CHART A1.

Installing DC "clamp-on" current sensors.



INSTALLATION
CHART A4

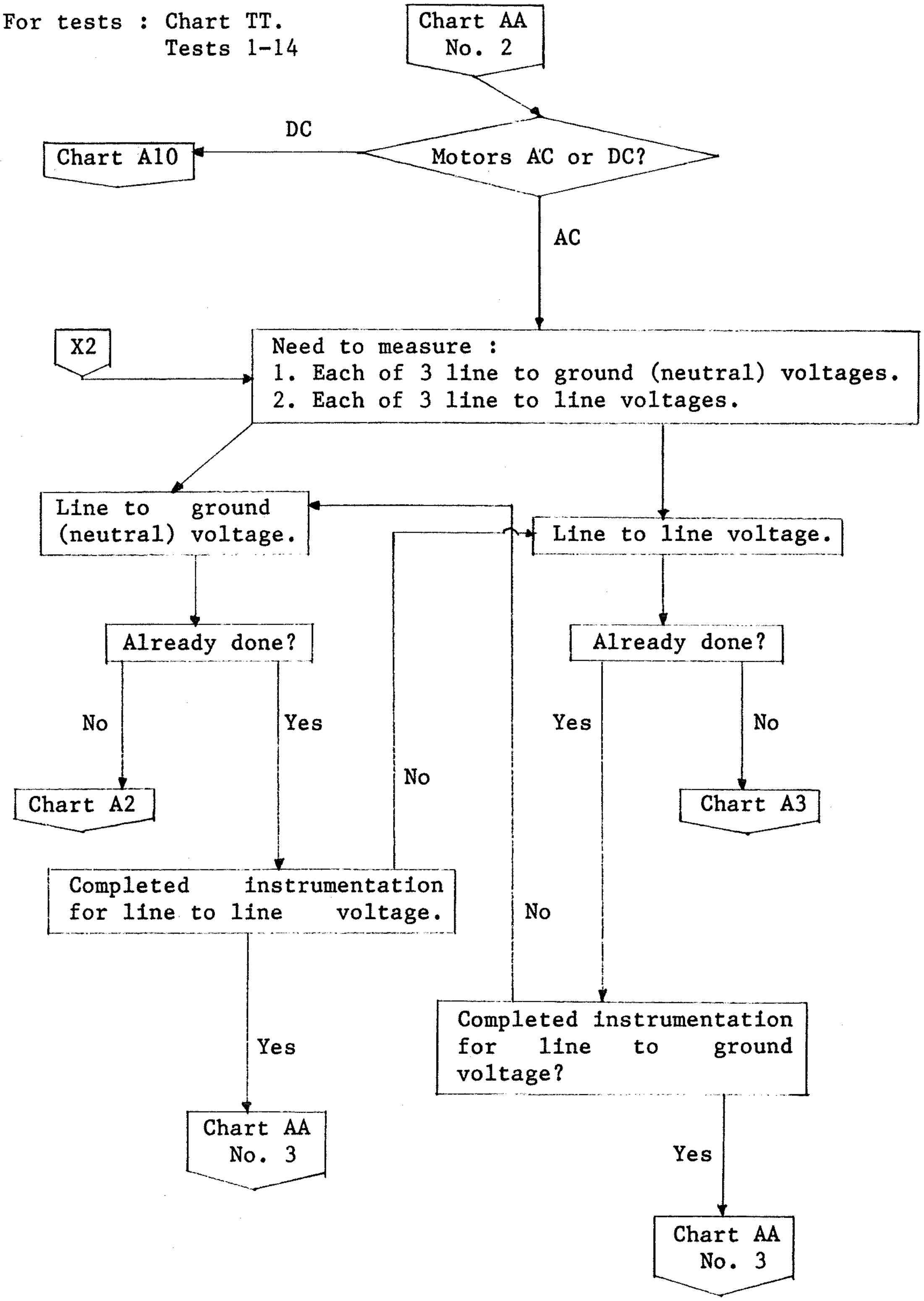
Installing AC "clamp-on" current sensors - drive motor rotor circuit.



INSTALLATION
CHART 5.

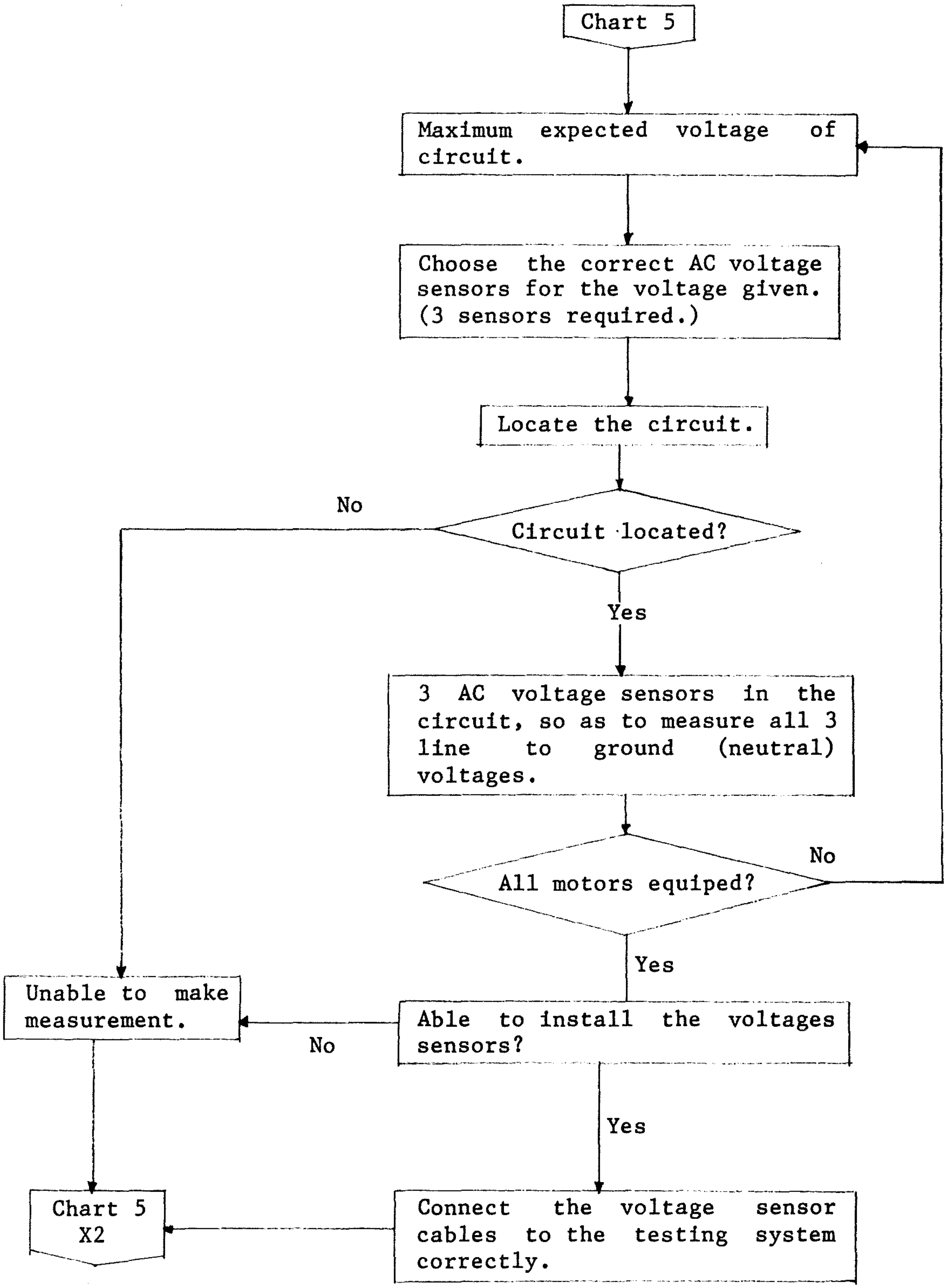
Measurement of motor voltages.

For tests : Chart TT.
Tests 1-14



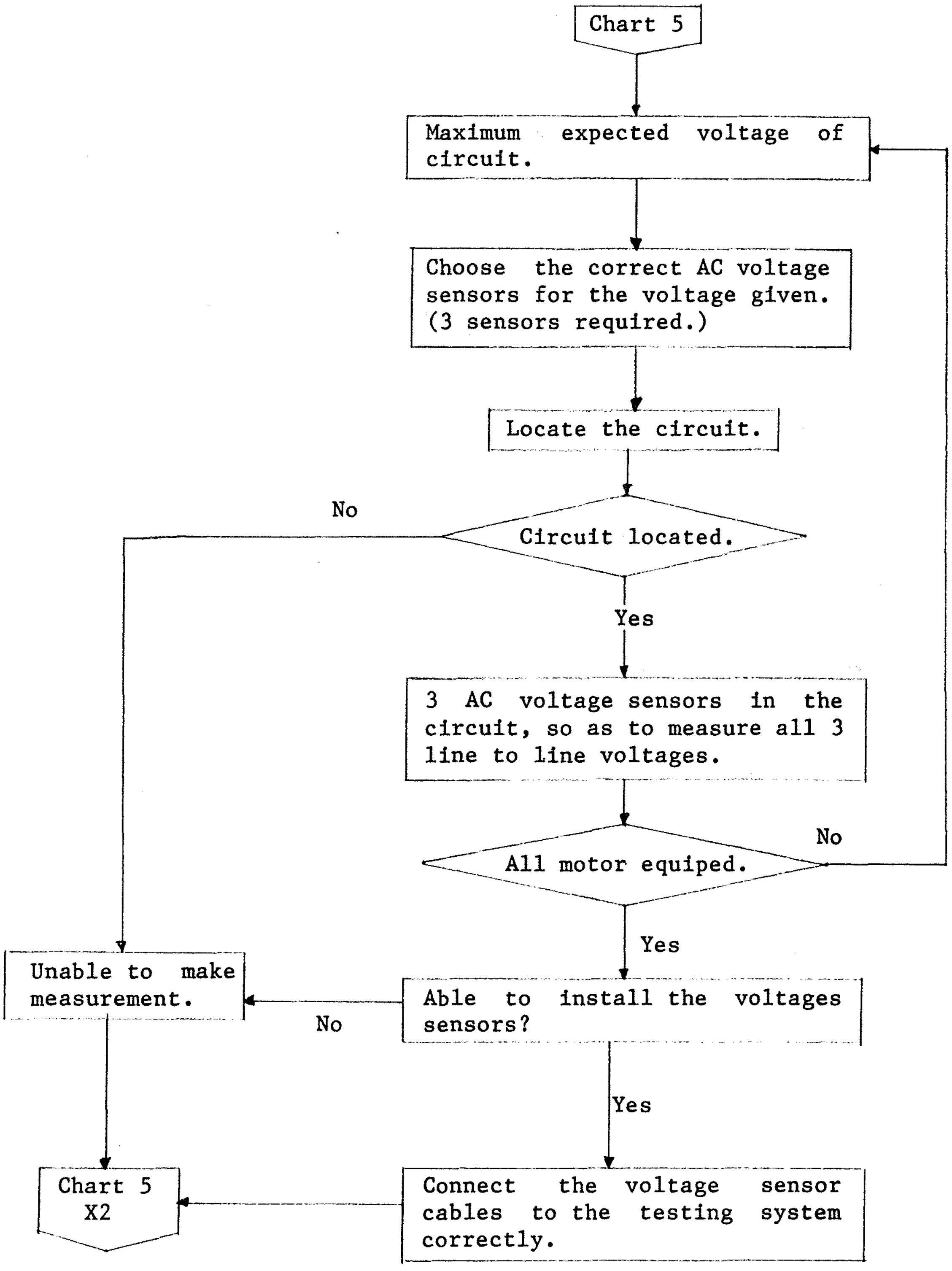
INSTALLATION
CHART A2.

Installing AC voltage sensors for line to ground voltage.



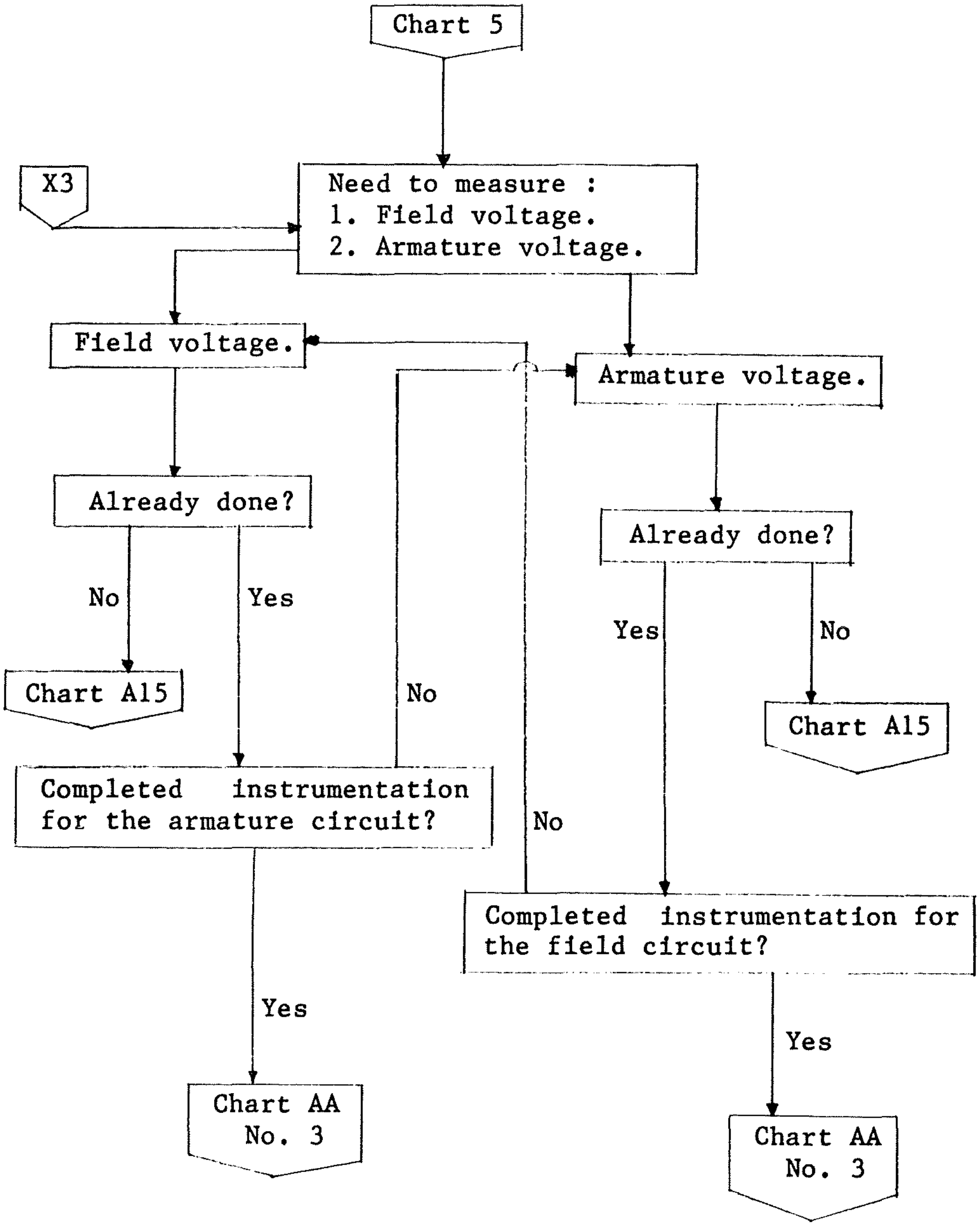
INSTALLATION
CHART A3.

Installing AC voltage sensors for line to line voltage.



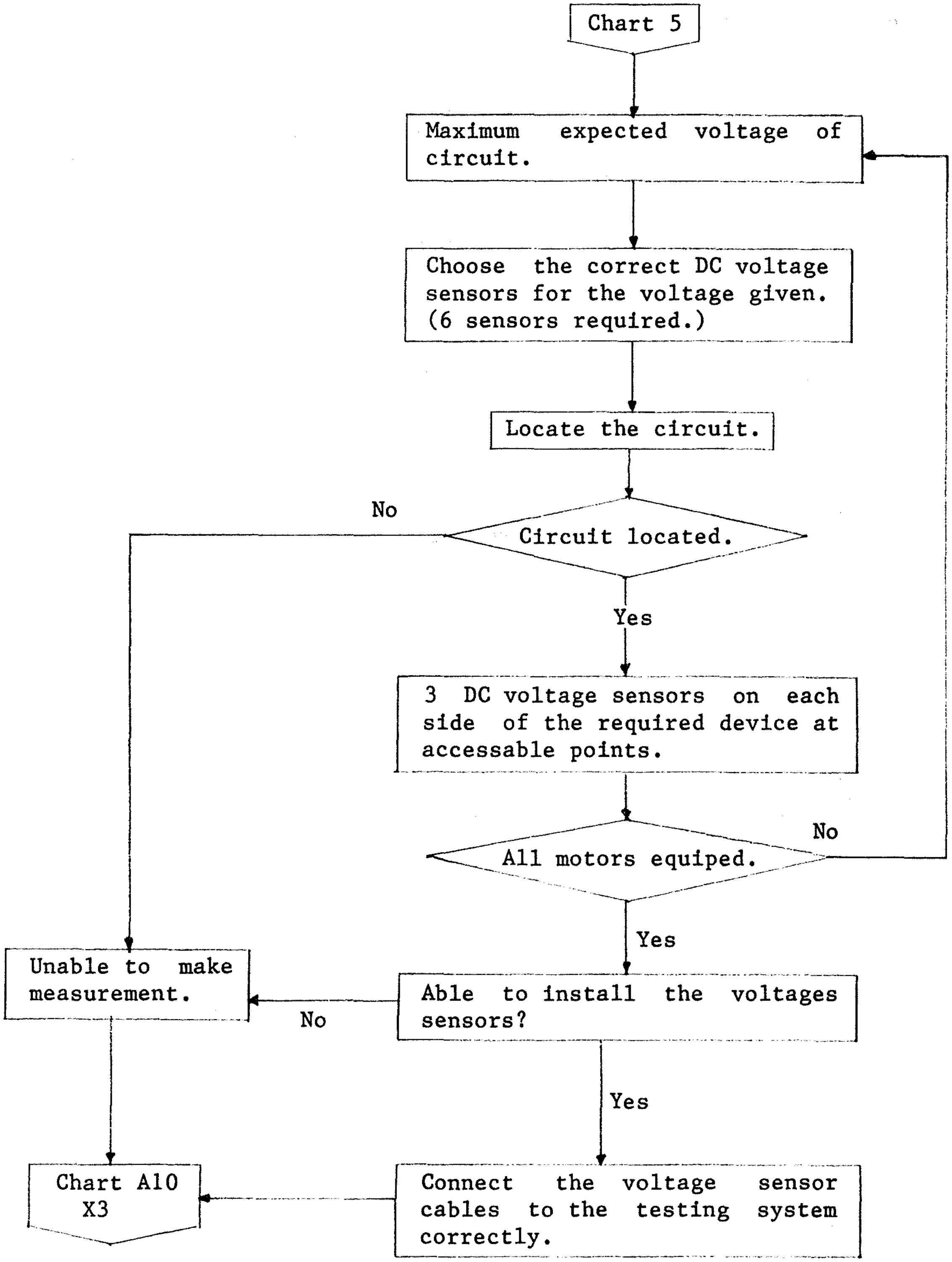
INSTALLATION
CHART A10.

Measurement of DC motor field and armature voltages.



INSTALLATION
CHART A15.

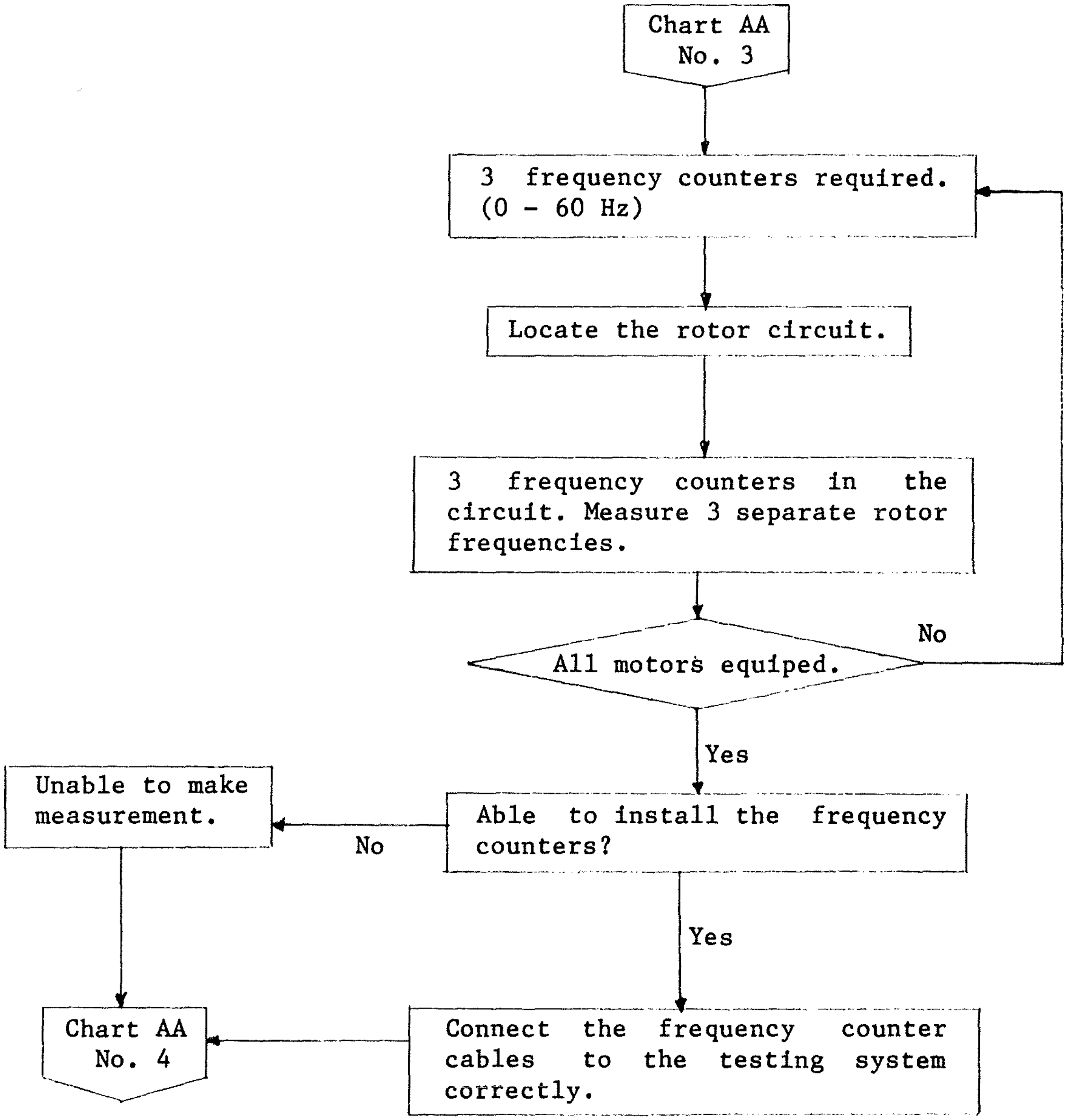
Installing DC voltage sensors.



INSTALLATION
CHART 7.

Measurement of AC motor rotor frequency.

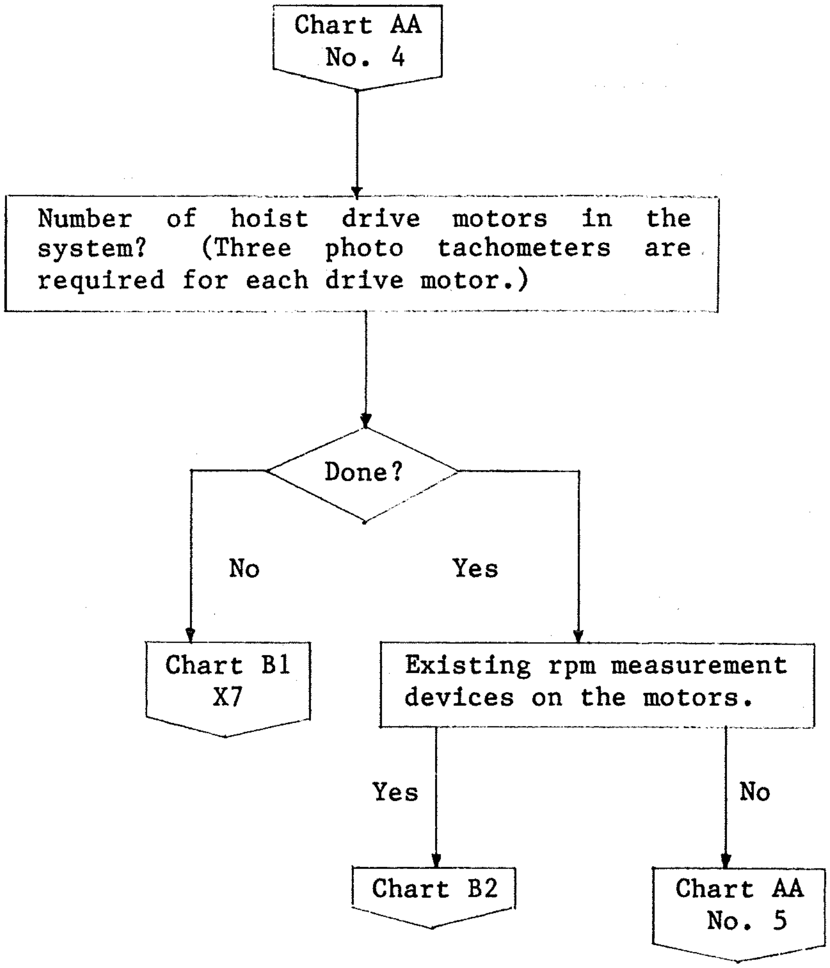
For tests : Chart TT. Tests 1,2,3,4,6,8.



INSTALLATION
CHART 8.

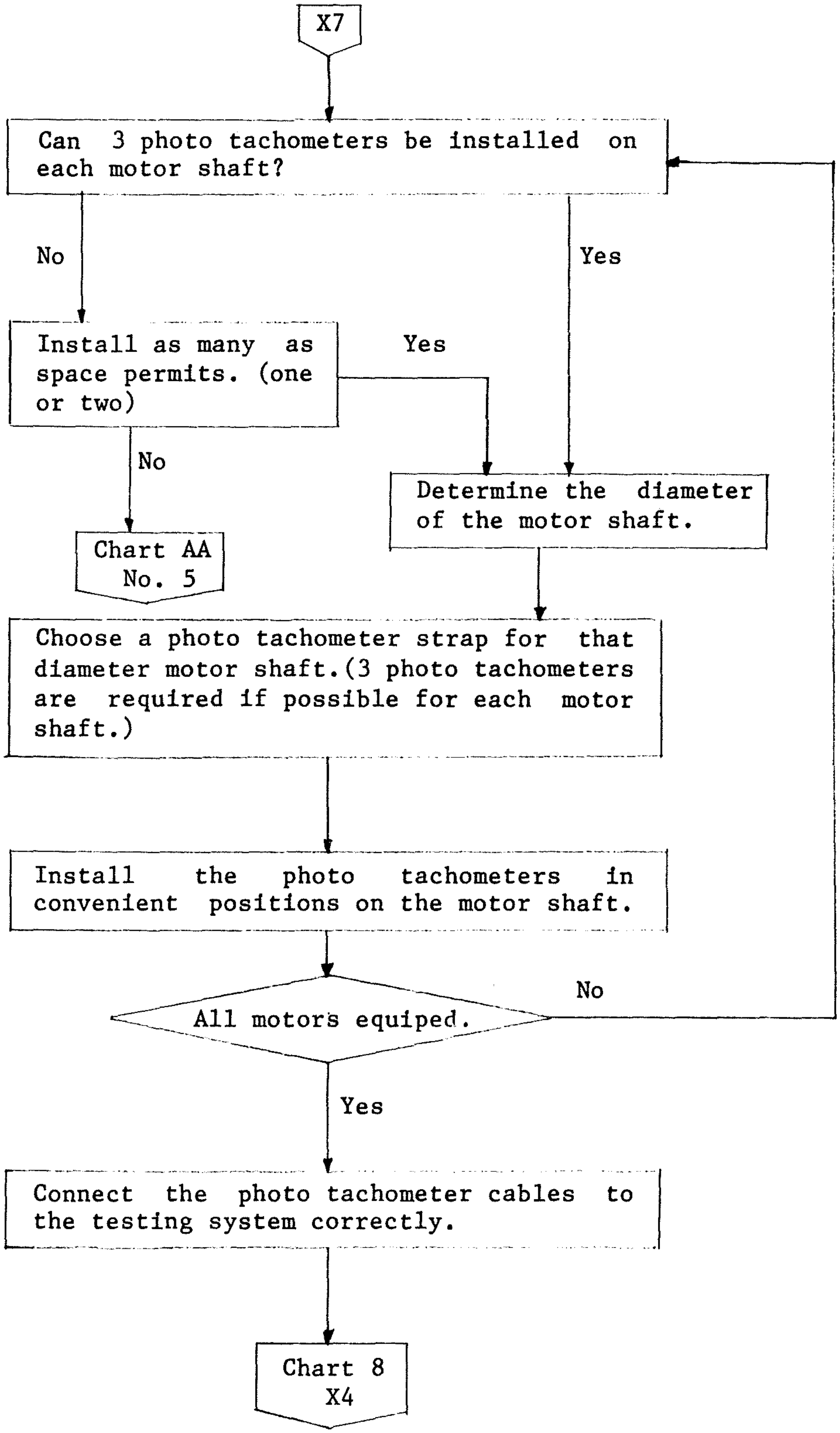
Installing photo tachometers for drive motor shaft.

For tests : Chart TT. Tests 1,2,3,4,12,13,14.



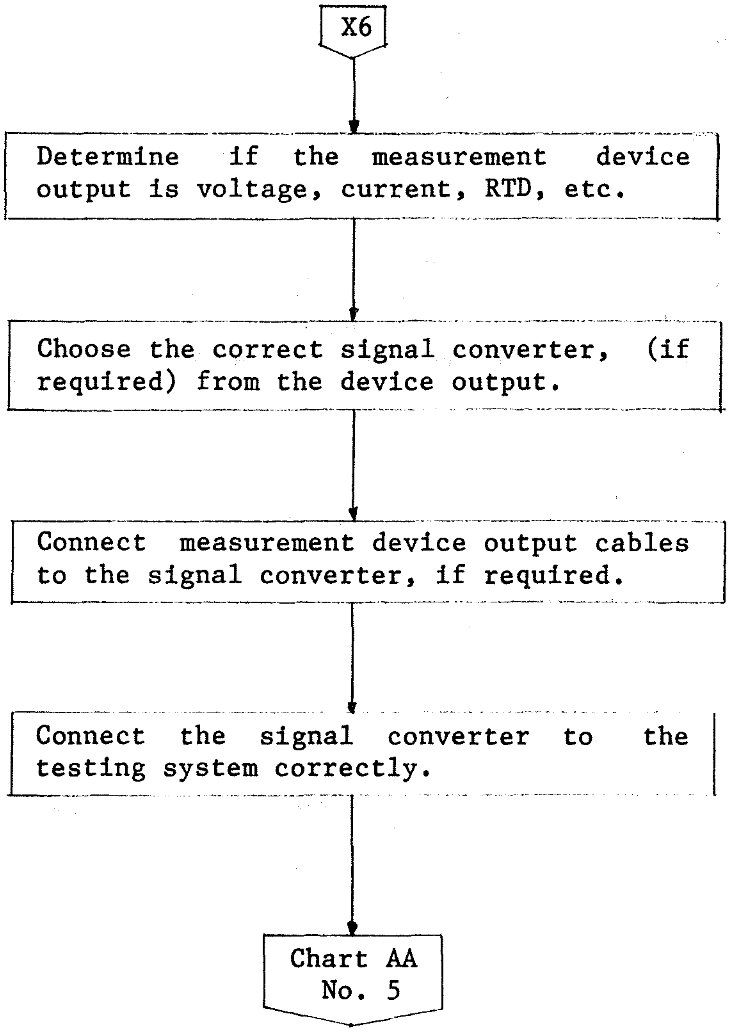
INSTALLATION
CHART B1.

Installation of a photo tachometer on a motor shaft.



INSTALLATION
CHART B2.

Connection of existing hoist measurement devices to the testing device.



INSTALLATION
CHART 10

Installation of accelerometers and "guide-rider" wheel packages on the conveyance

For tests : Chart TT. 1,3,4,6,7,8,9,10,11,12,13.

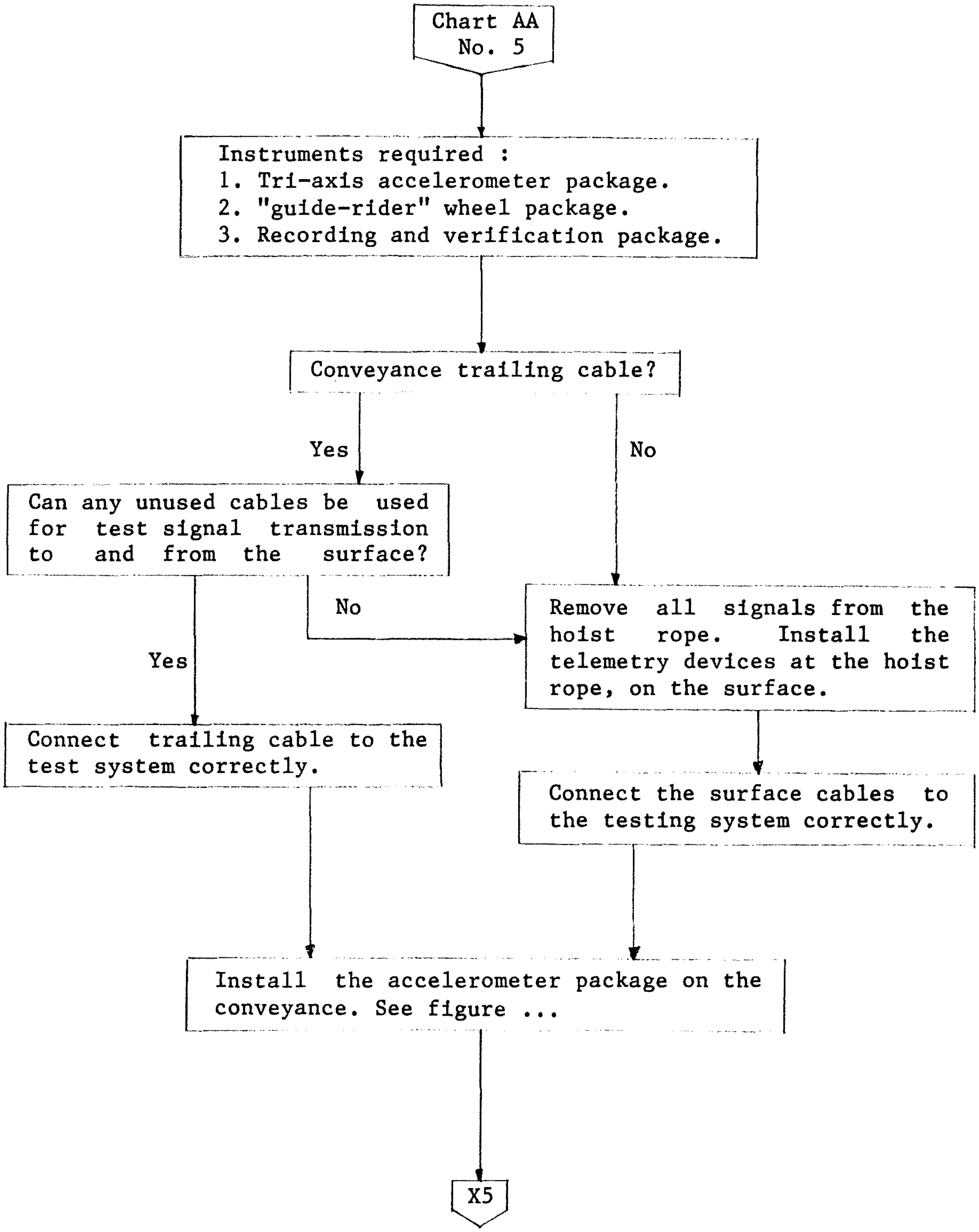
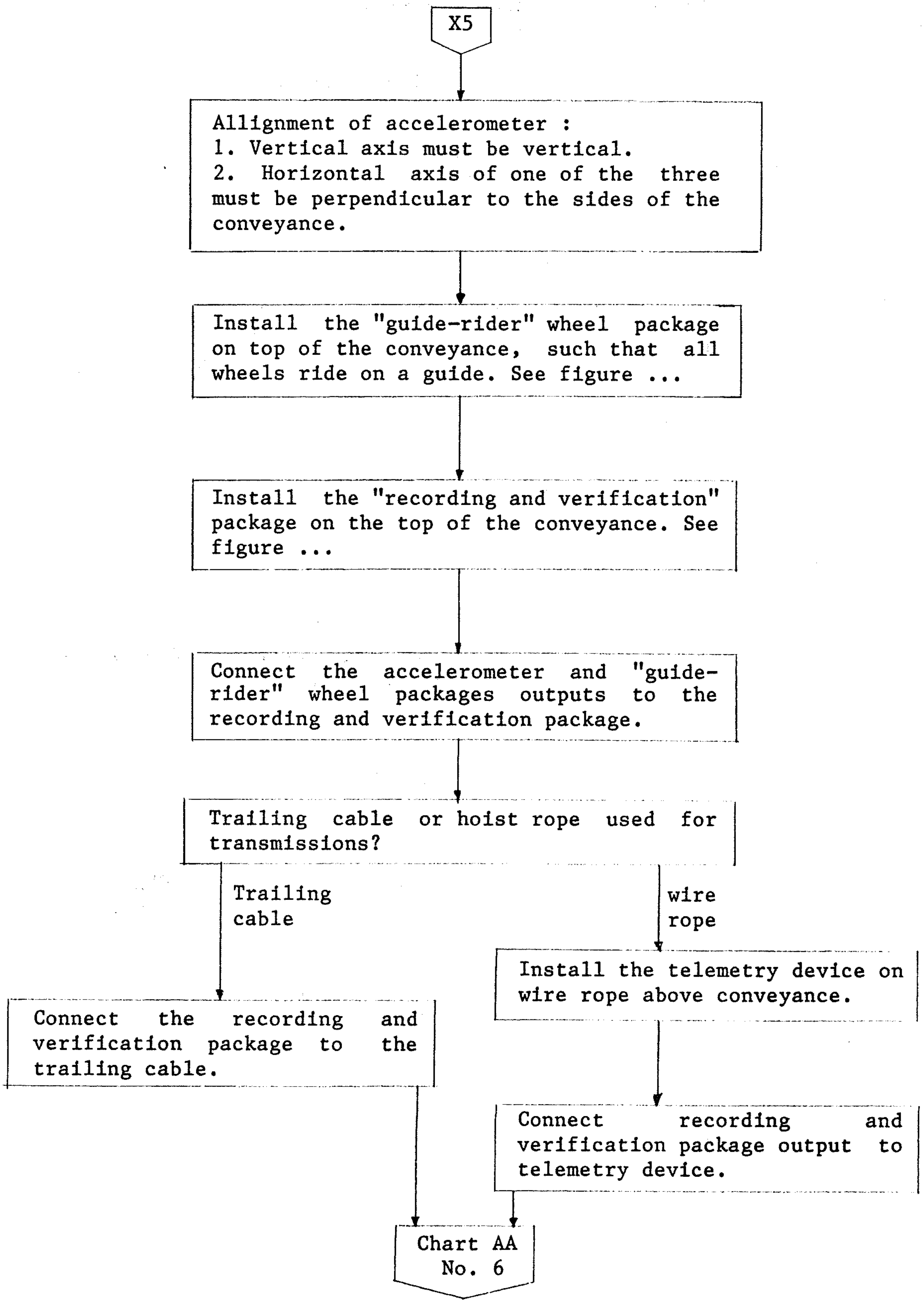


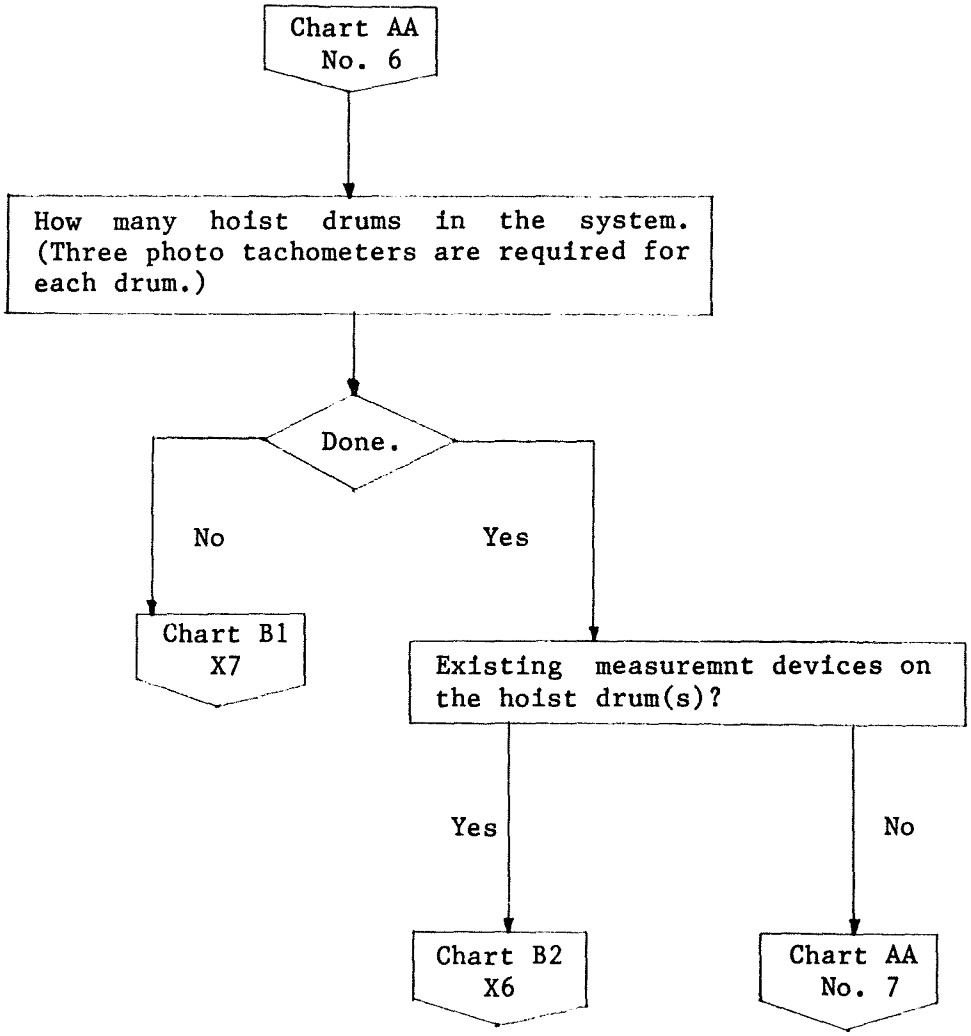
Chart 10, Continued.



INSTALLATION
CHART 30.

Measurement of hoist drum rotational properties.

For tests : Chart TT. Tests 1,3,4,5,6,7,8,9,10,11,14.



INSTALLATION
CHART 40.

Installing the rope tension device.

For tests : Chart TT. Tests 1,3,4,6,8.

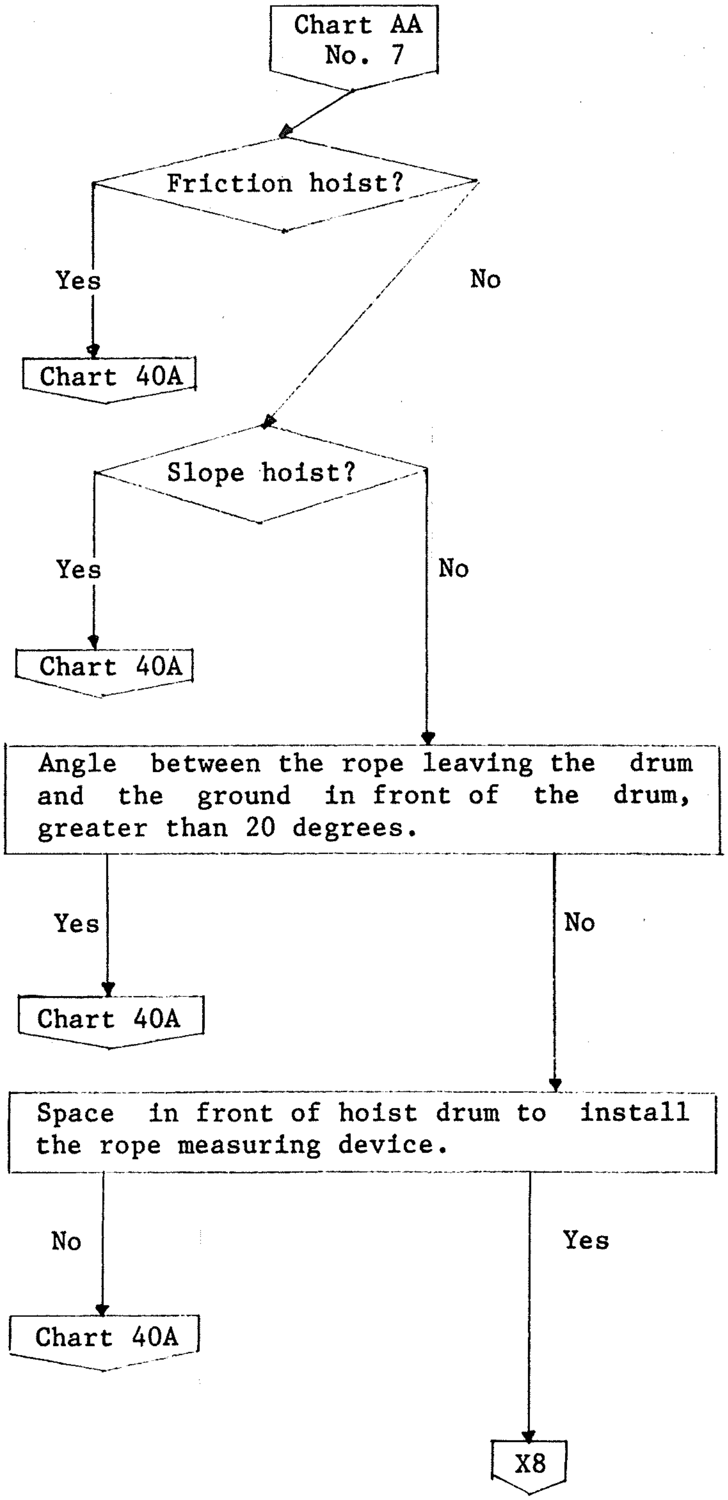
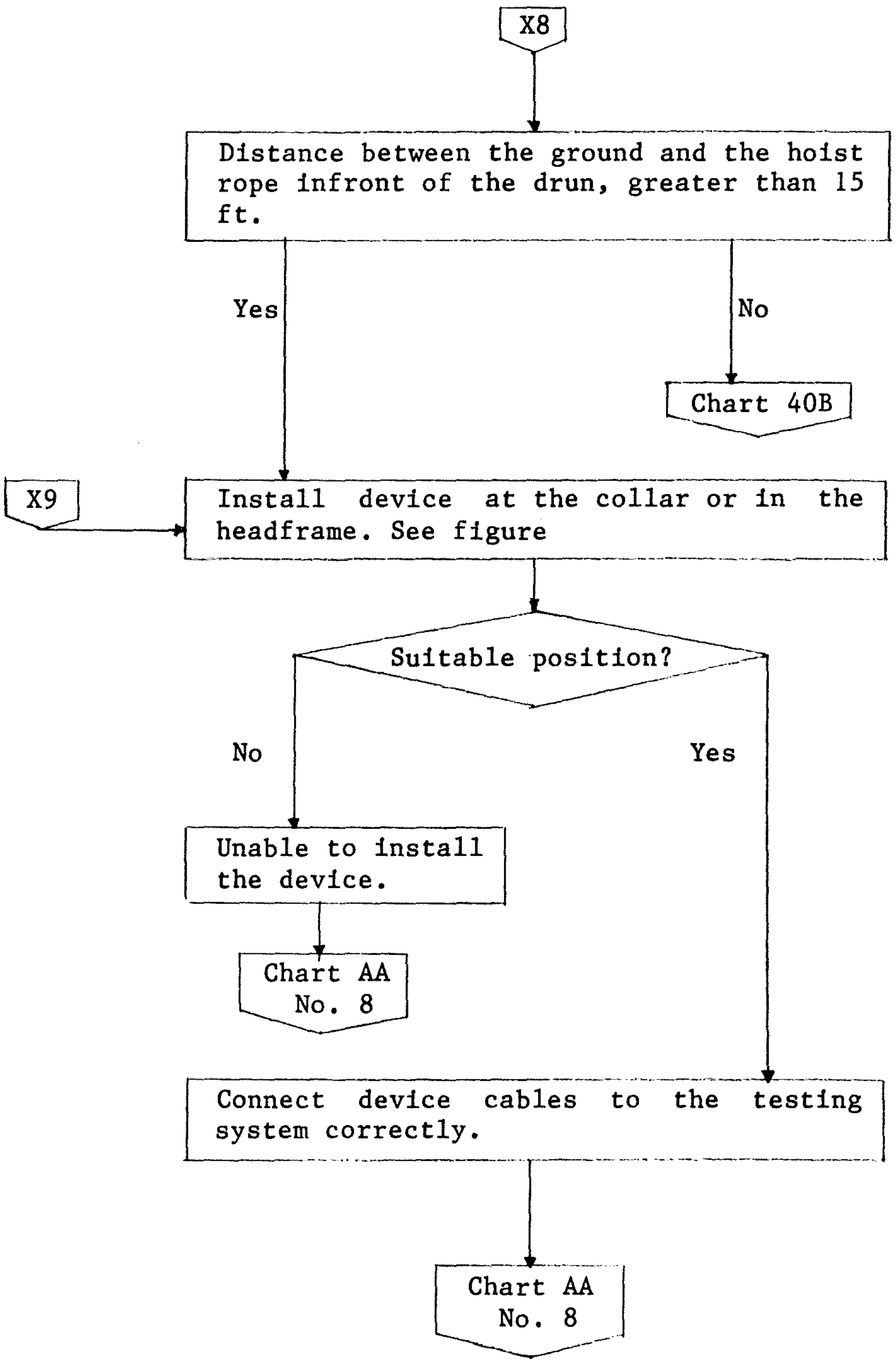


Chart 40, continued.



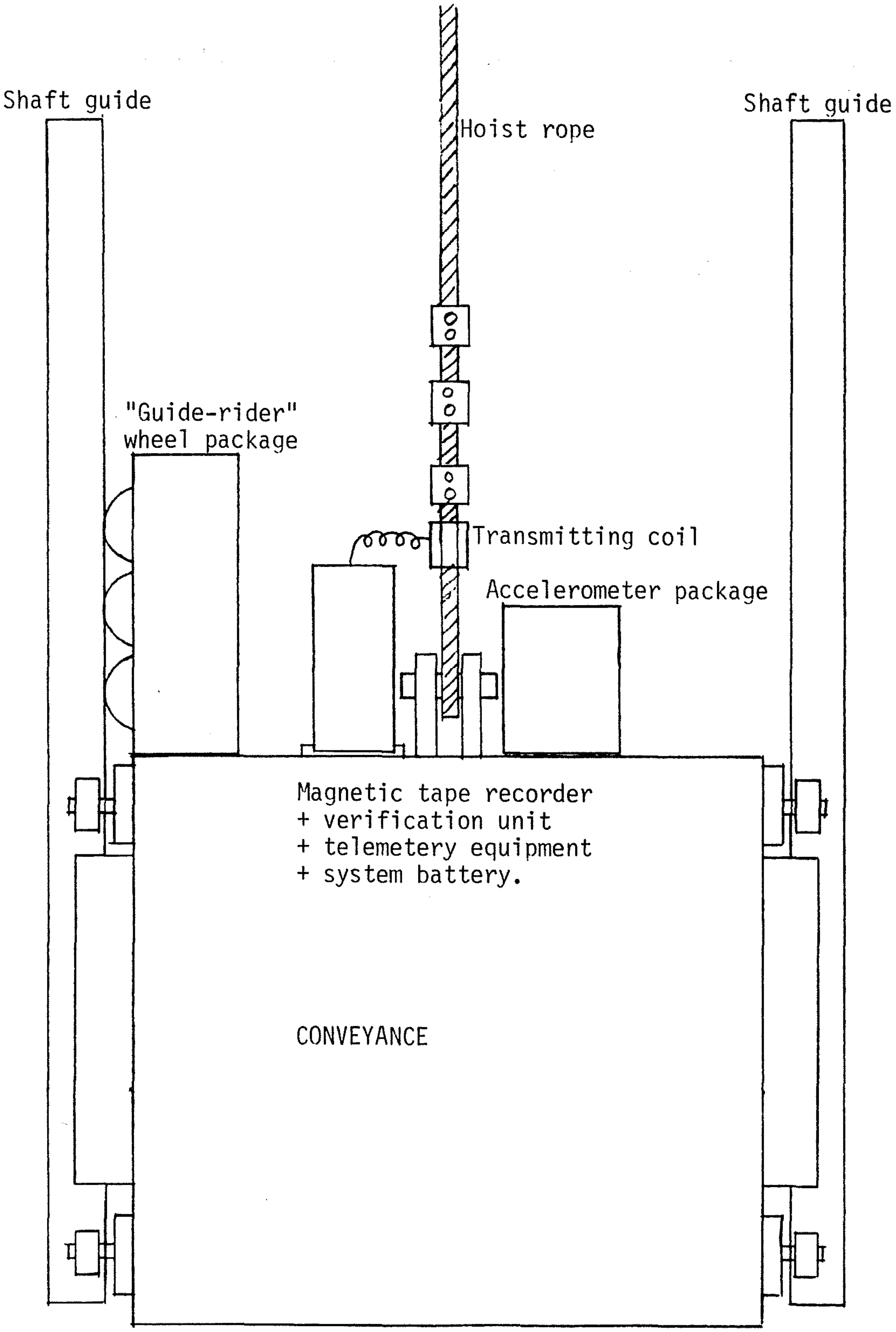
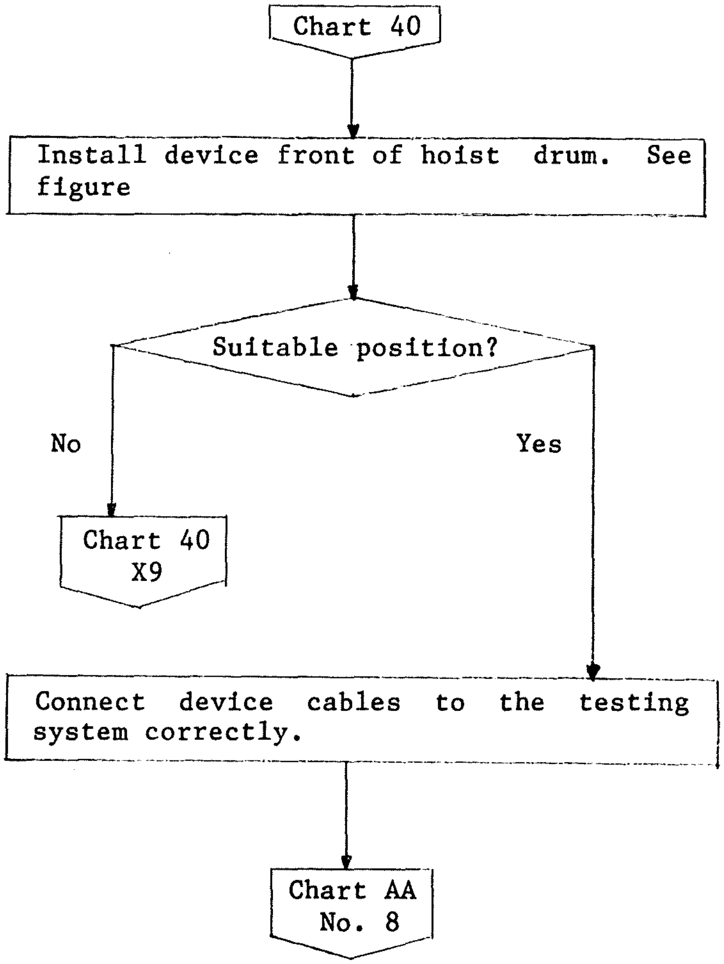


Figure A1 - Typical conveyance instrumentation.

INSTALLATION
CHART 40B.

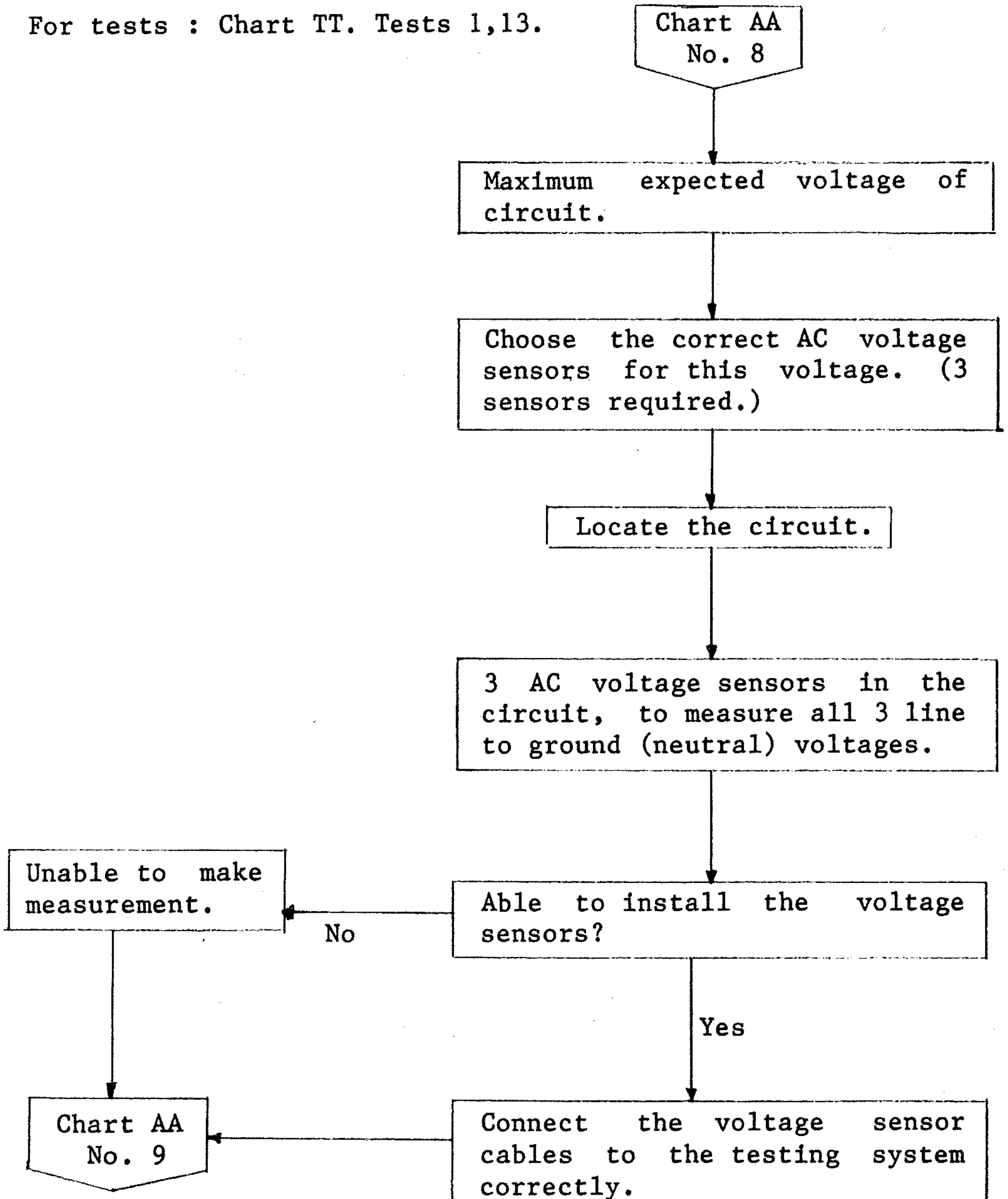
Installing rope tension measuring device at the hoist drum.



INSTALLATION
CHART 50.

Monitoring hoist feeder power.

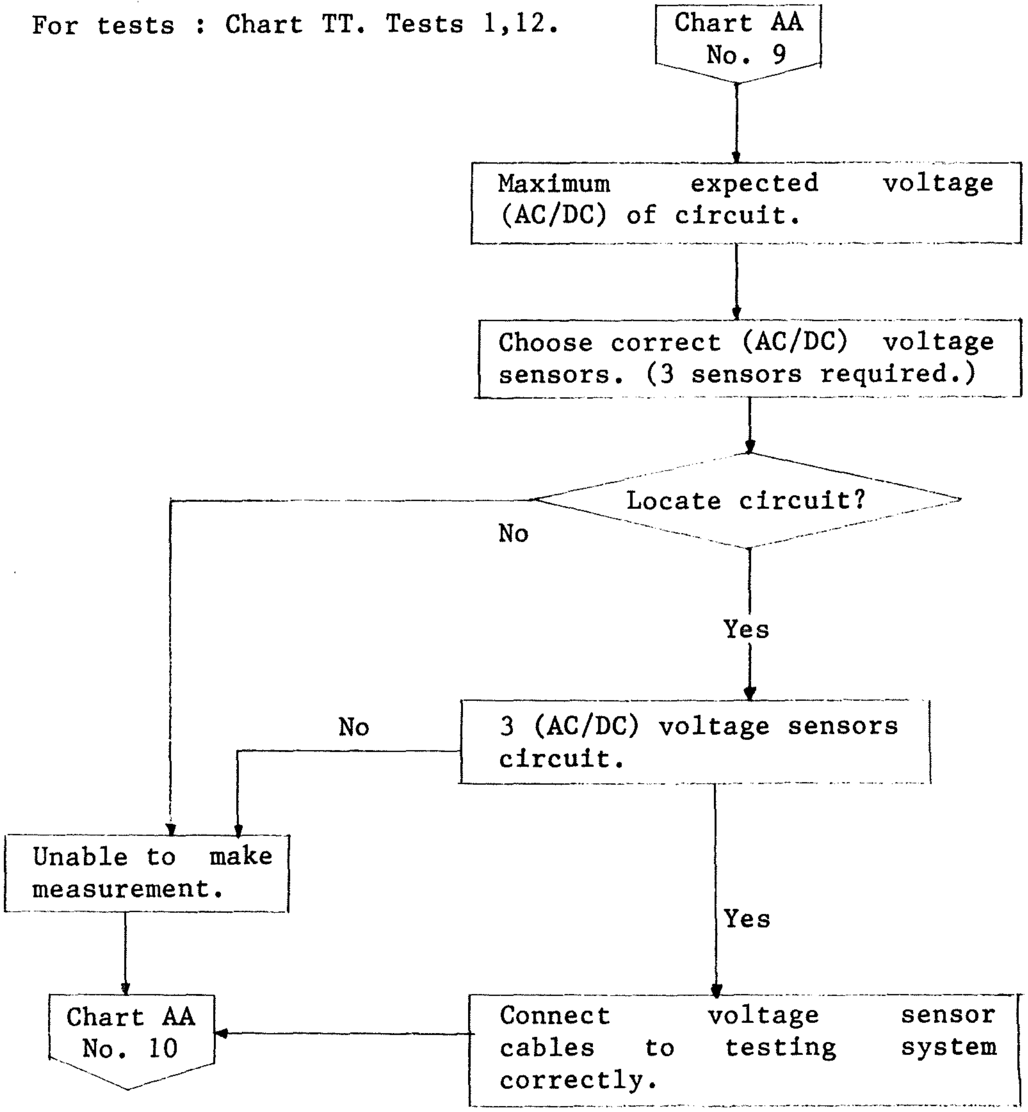
For tests : Chart TT. Tests 1,13.



INSTALLATION
CHART 60.

Monitoring hoist control power.

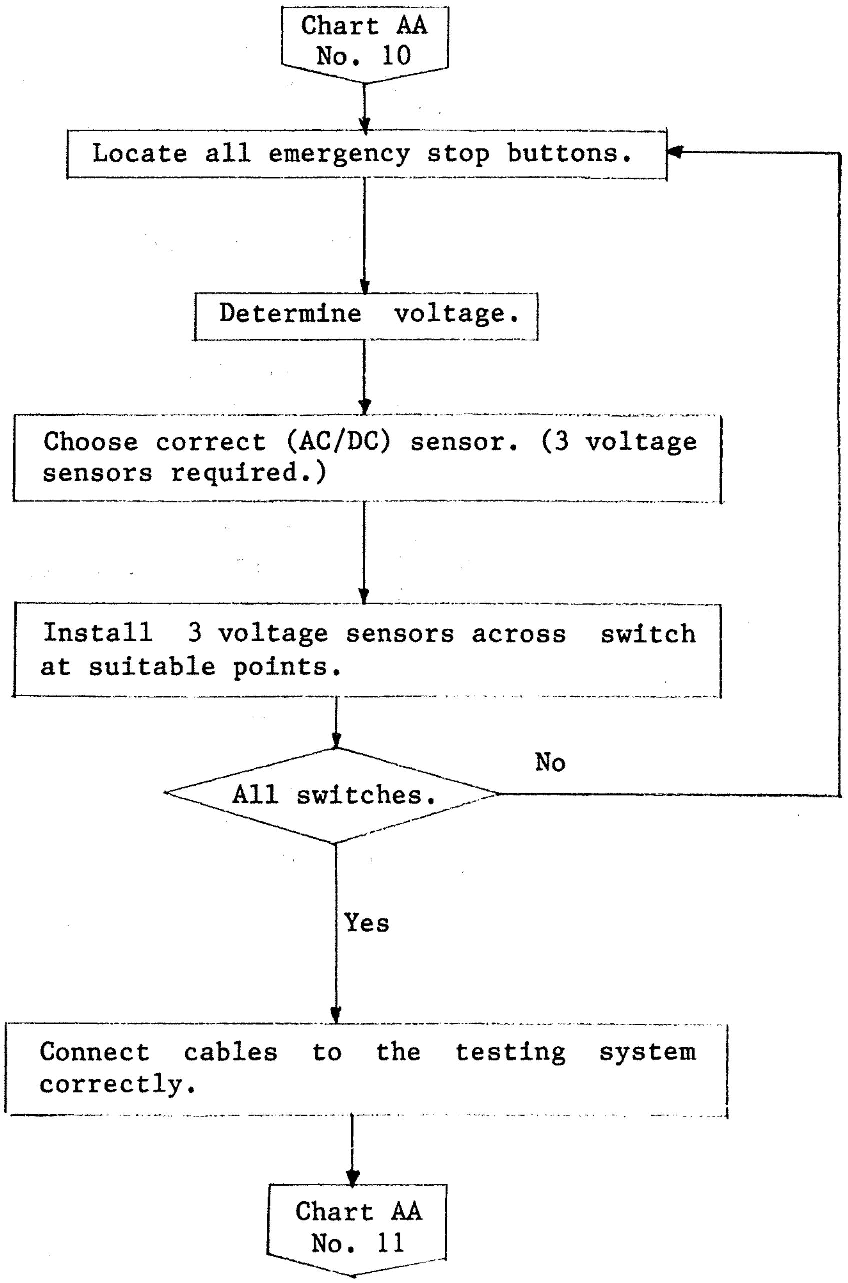
For tests : Chart TT. Tests 1,12.



INSTALLATION
CHART 80.

Monitoring Emergency stop buttons.

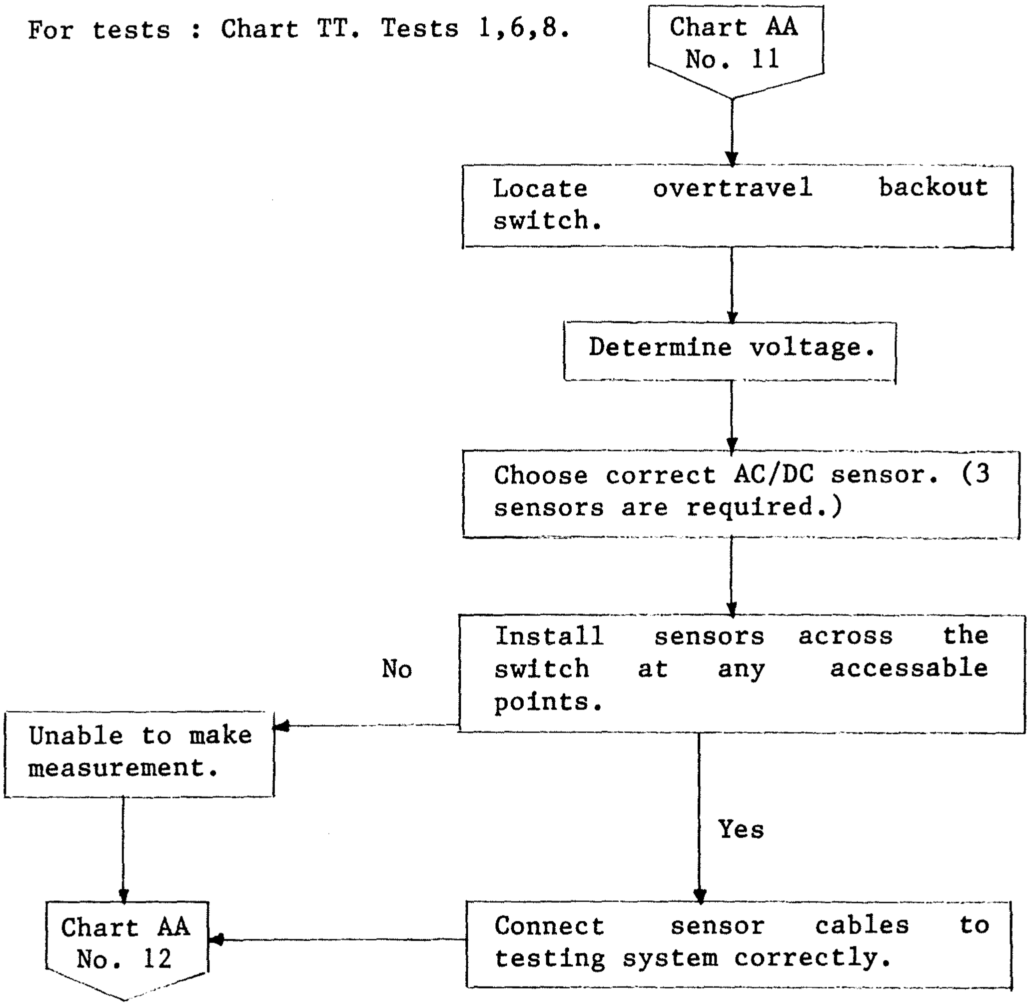
For tests : Chart TT. Tests 1,2,5,6,7,8,9,10,11,12,13,14.



INSTALLATION
CHART 90.

Monitor the overtravel backout switch.

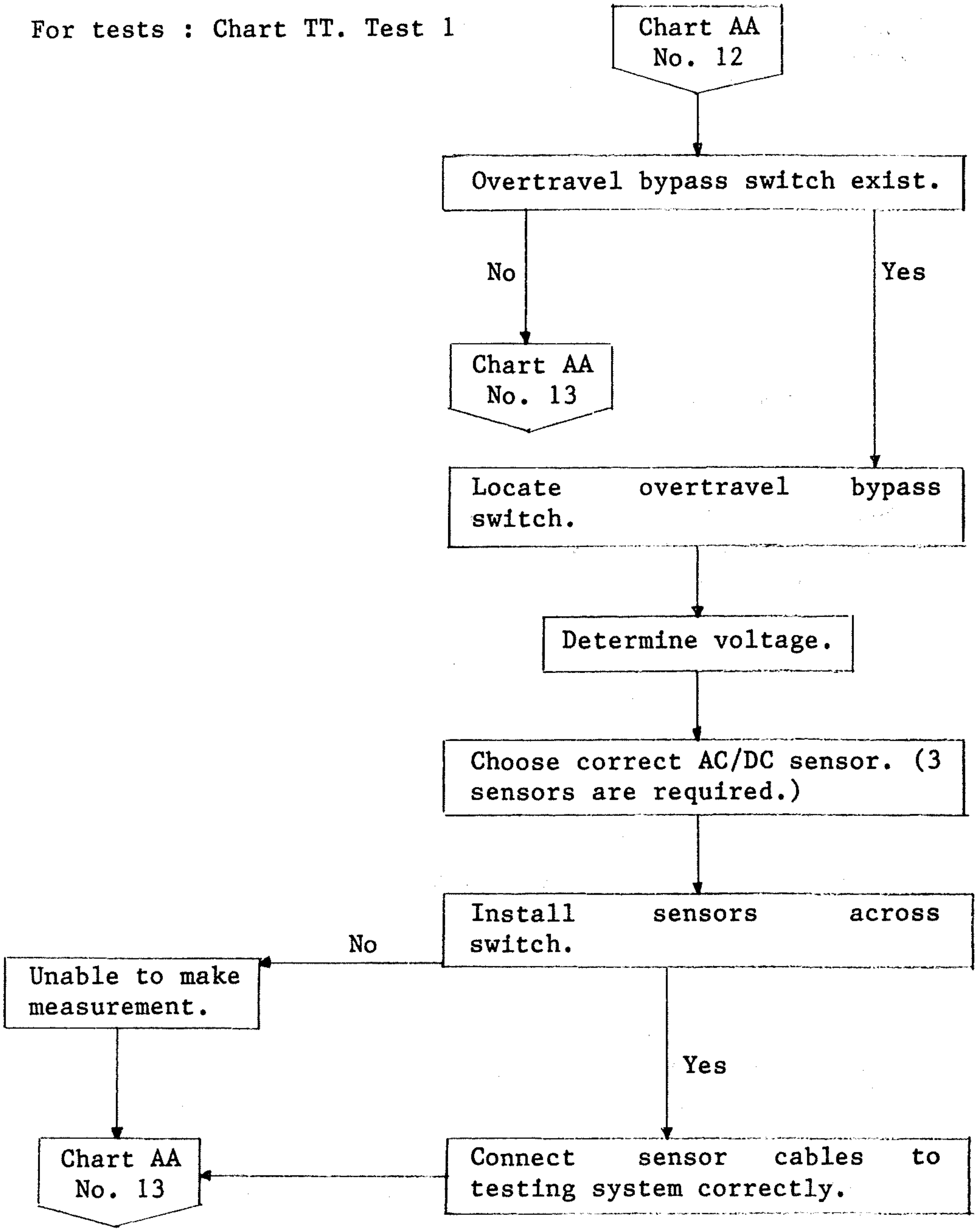
For tests : Chart TT. Tests 1,6,8.



INSTALLATION
CHART 100.

Monitoring the overtravel bypass switch.

For tests : Chart TT. Test 1



INSTALLATION
CHART 110.

Monitoring the overtravel and overspeed devices.

For tests : Chart TT.
Tests 1,6,8,11.

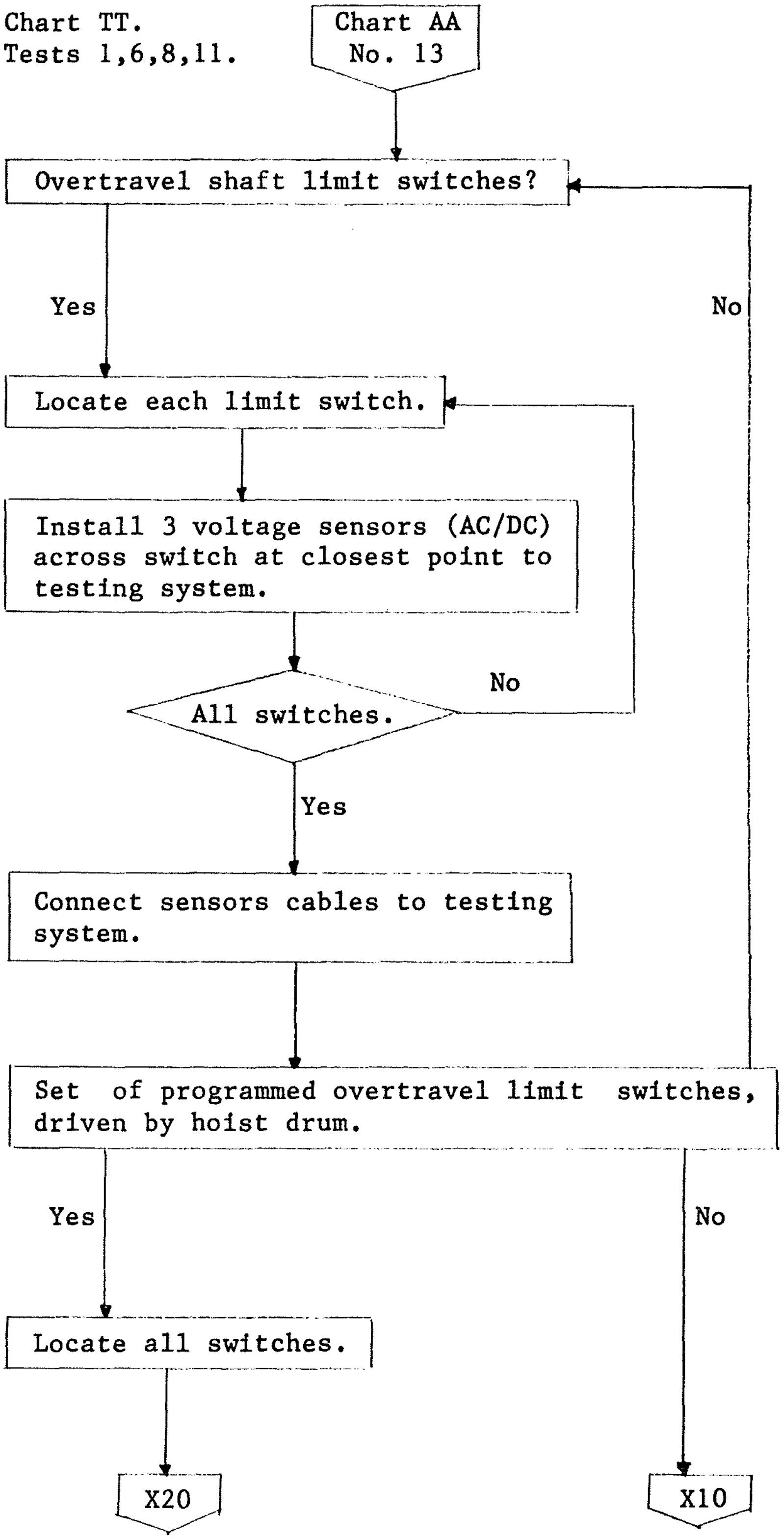
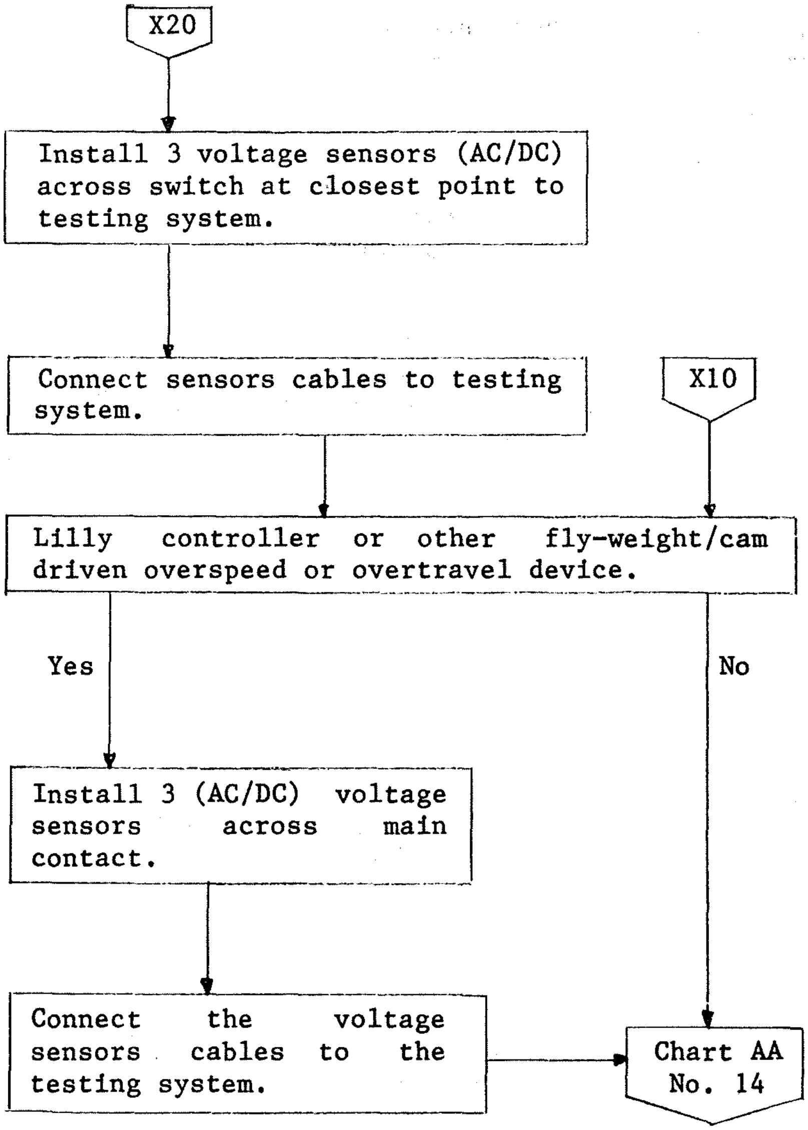


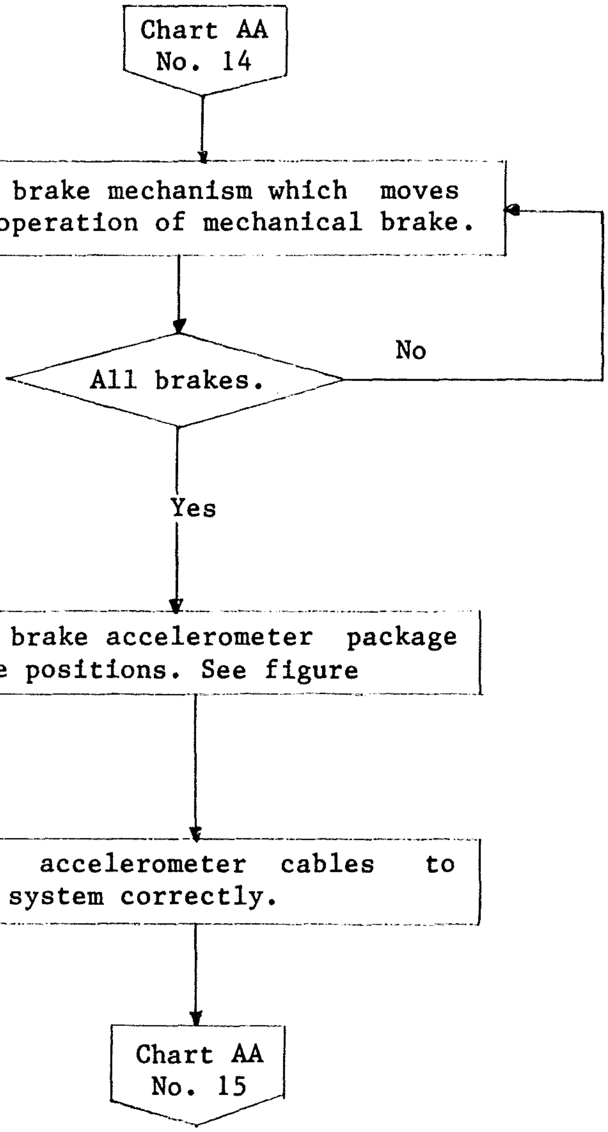
Chart 110, continued.



INSTALLATION
CHART 120.

Installing the brake movement sensor.

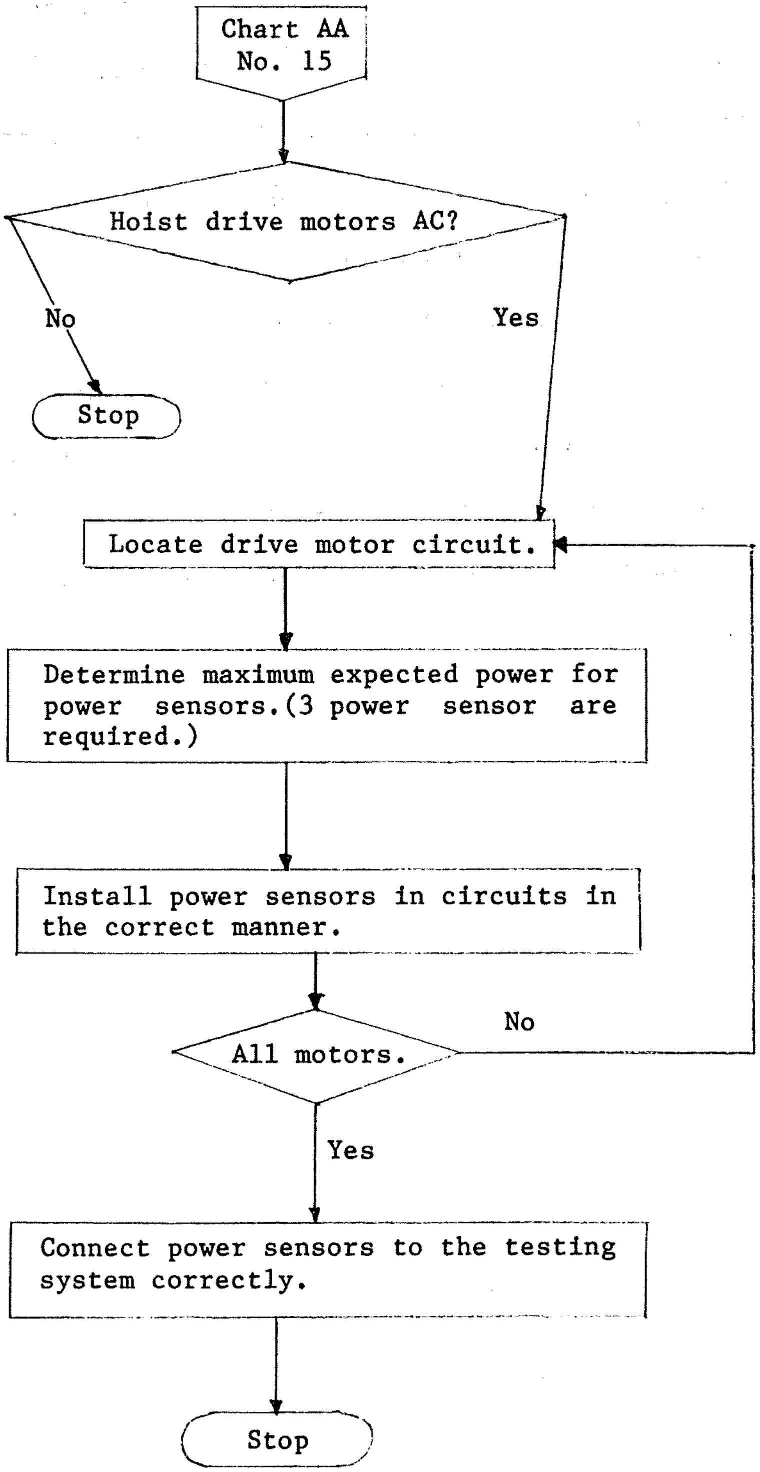
For tests : Chart TT. Tests 1-14.



INSTALLATION
CHART 130.

Measurement of AC drive motor power.

For tests : Chart TT. Tests 1,2,3,4,5,7,9,11.



APPENDIX 3.

Inspection Test Instructional Flowcharts.

The instructional flowcharts are designed to guide an mine inspector or operator through the procedure for conducting the inspection tests. The flowcharts guide the inspection personnel through the steps required to complete each test. Qualified personnel at the mine should operate the hoist during the test.

The flowcharts are designed to be followed in sequence. Once the instrumentation requirements have been completed, the inspection tests are to be conducted in sequence. This would be the most desirable inspection method. However, if the desire is to conduct an individual test , the test flowcharts contain a desciption of the test equipment required for that test.

Contents.

CHART TT

Test flowcharts.

Test no. :	Test name.	Go to Chart no.
1	Operation of hoist through standard cycle.	TA1
2	First emergency stop test.	TA2
3	First and second standard operating stop.	TA3
4	Third standard operating stop.	TA4
5	Second emergency stop test.	TA5
6	Overtravel and overtravel backout switch test. (for undertravel only)	TA6
7	Third emergency stop test.	TA7
8	Overtravel and overtravel backout switch test. (for overtravel only)	TA8
9	Fourth emergency stop test.	TA9
10	"Deadman" controller test.	TB1

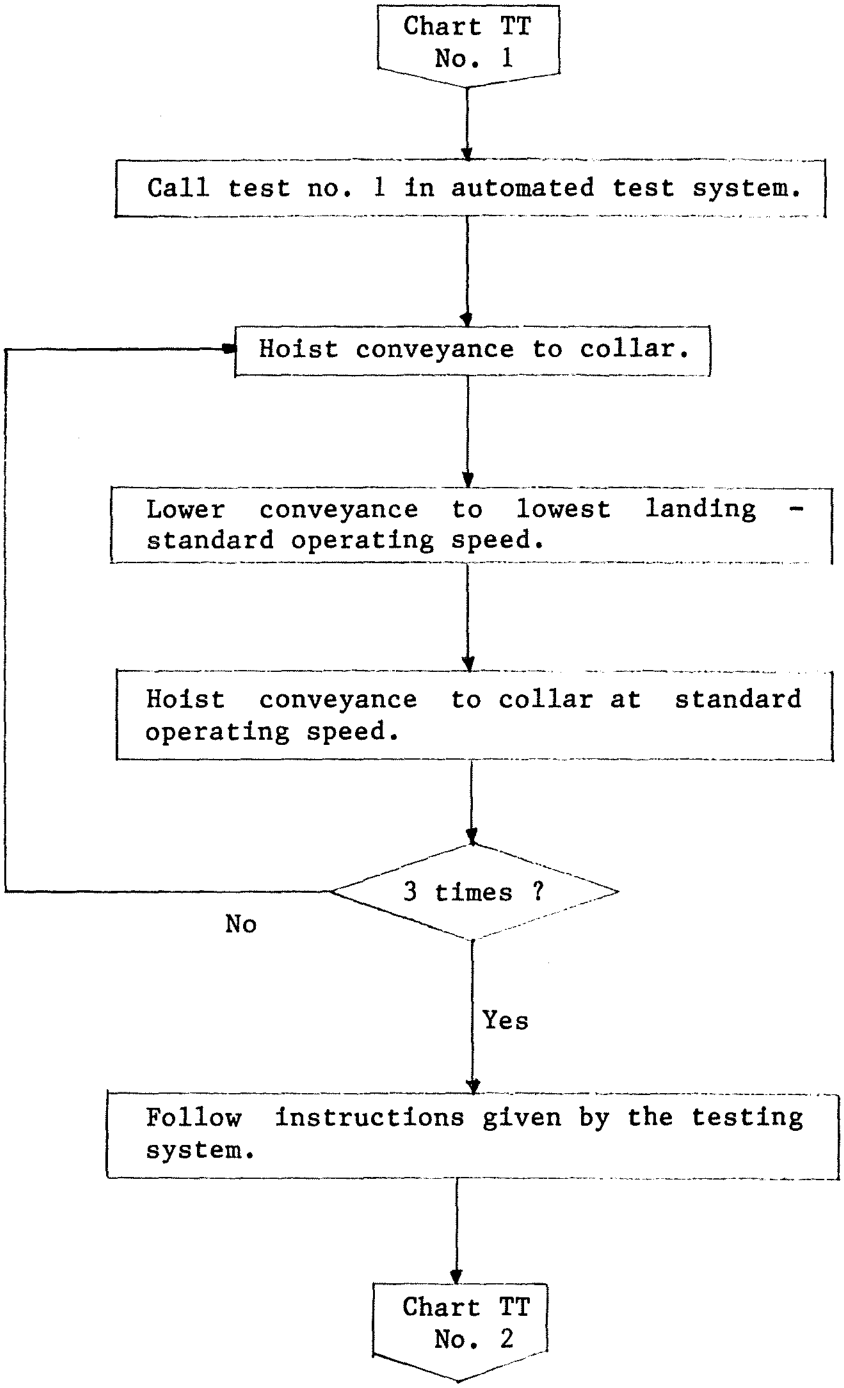
CHART TT, CONTINUED.

Test no. :	Test name.	Go to Chart no.
11	Last emergency stop and overspeed test.	TB2
12	Control power loss.	TB3
13	Feeder power loss.	TB4
14	DC motor field loss.	TB5

TESTING
CHART TA1.

Test no. 1 : Standard hoisting cycle.

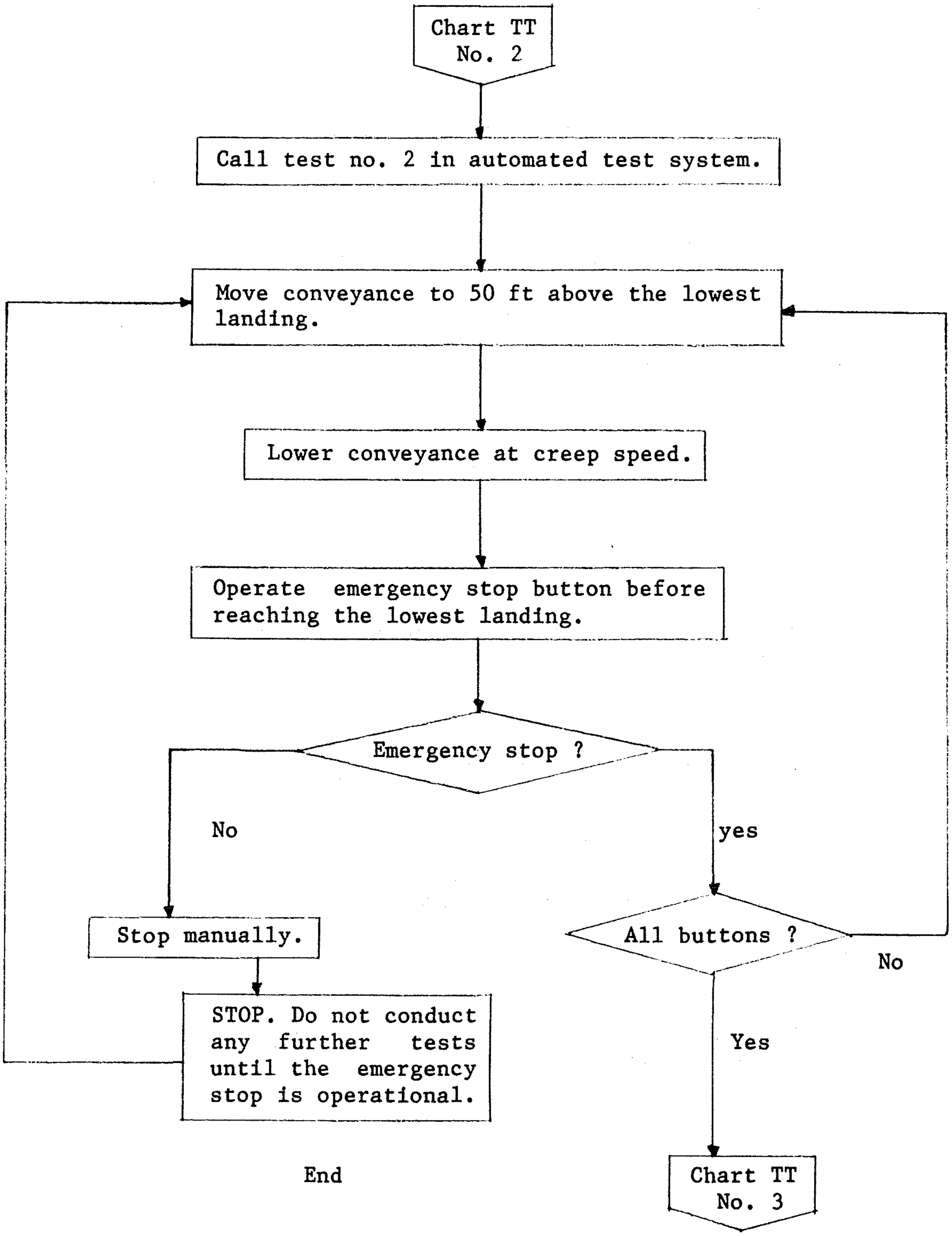
Required instrumentation : Chart AA, Installations 1 - 15.



TESTING
CHART TA2.

Test no. 2 : First emergency stop test.

Required instrumentation : Chart AA,
Installations 1,2,3,4,10,14,15.



TESTING
CHART TA3.

Test no. 3 : First and second standard operating stop.

Required instrumentation : Chart AA,
Installations 1,2,3,4,5,6,7,14,15.

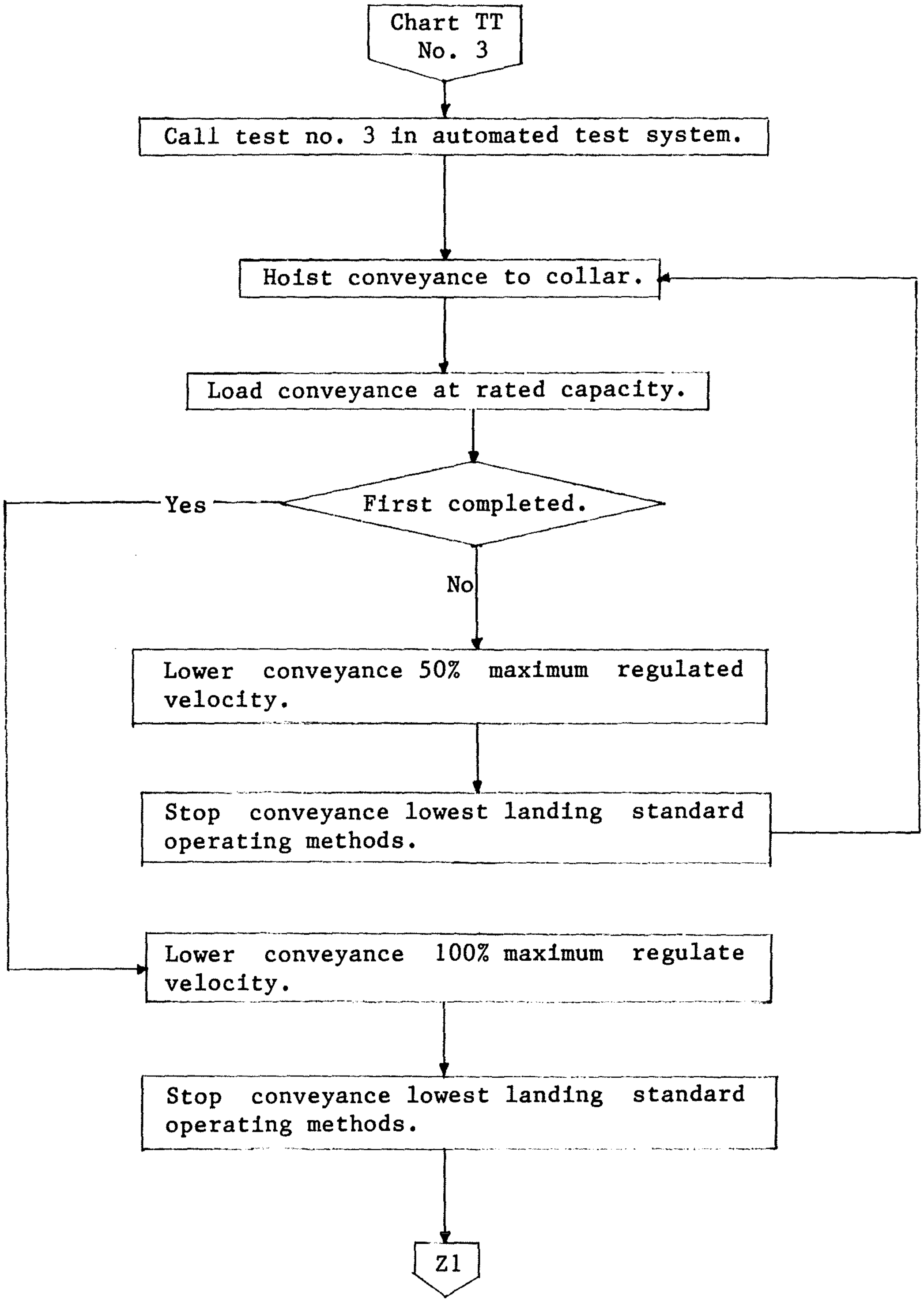
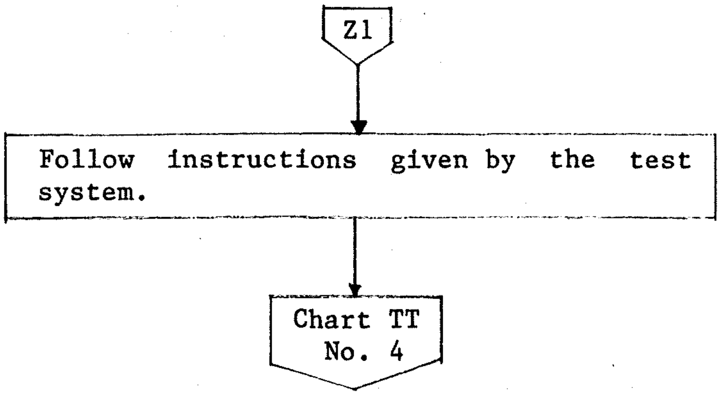


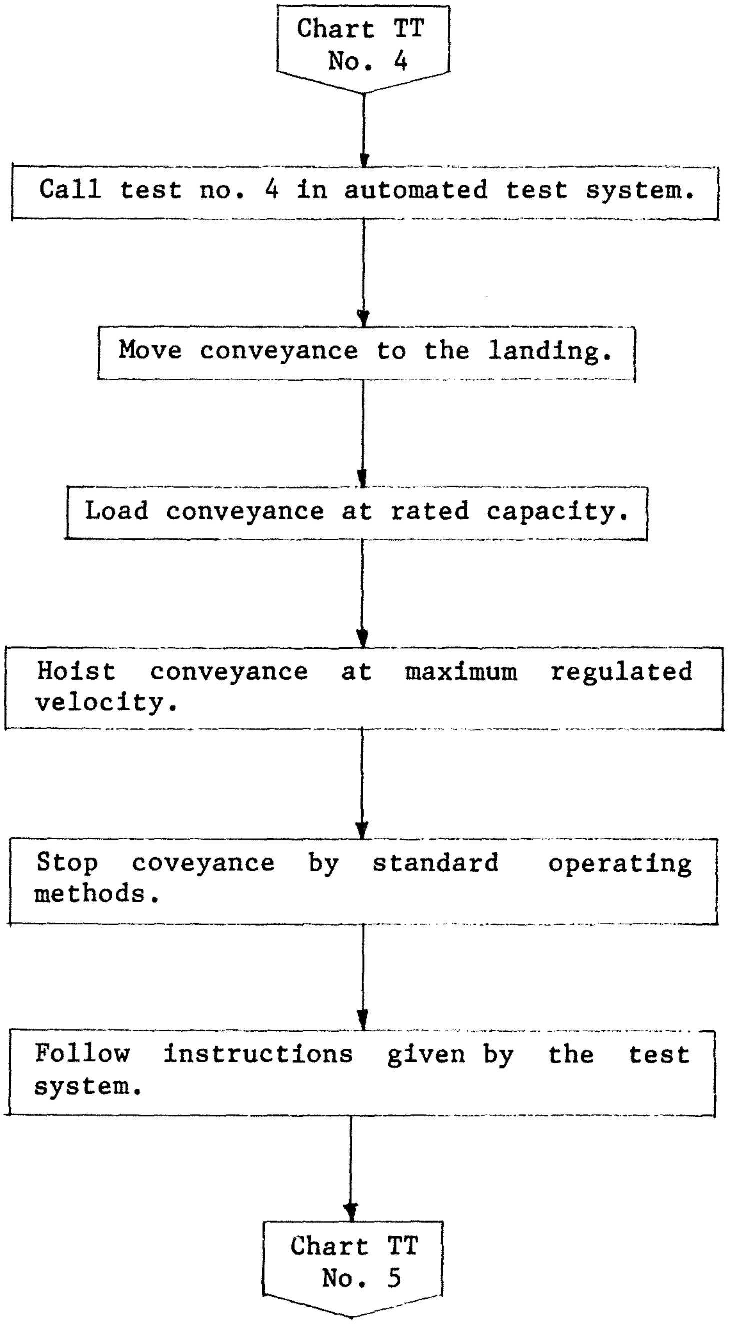
Chart TA3, continued.



TESTING
CHART TA4.

Test no. 4 : Third standard operating stop.

Required instrumentation : Chart AA,
Installations 1,2,3,4,5,6,7,14,15.



TESTING
CHART TA5.

Test no. 5 : Second emergency stop test.

Required Instrumentation :
Chart AA, Installations
1,2,5,6,10,14,15.

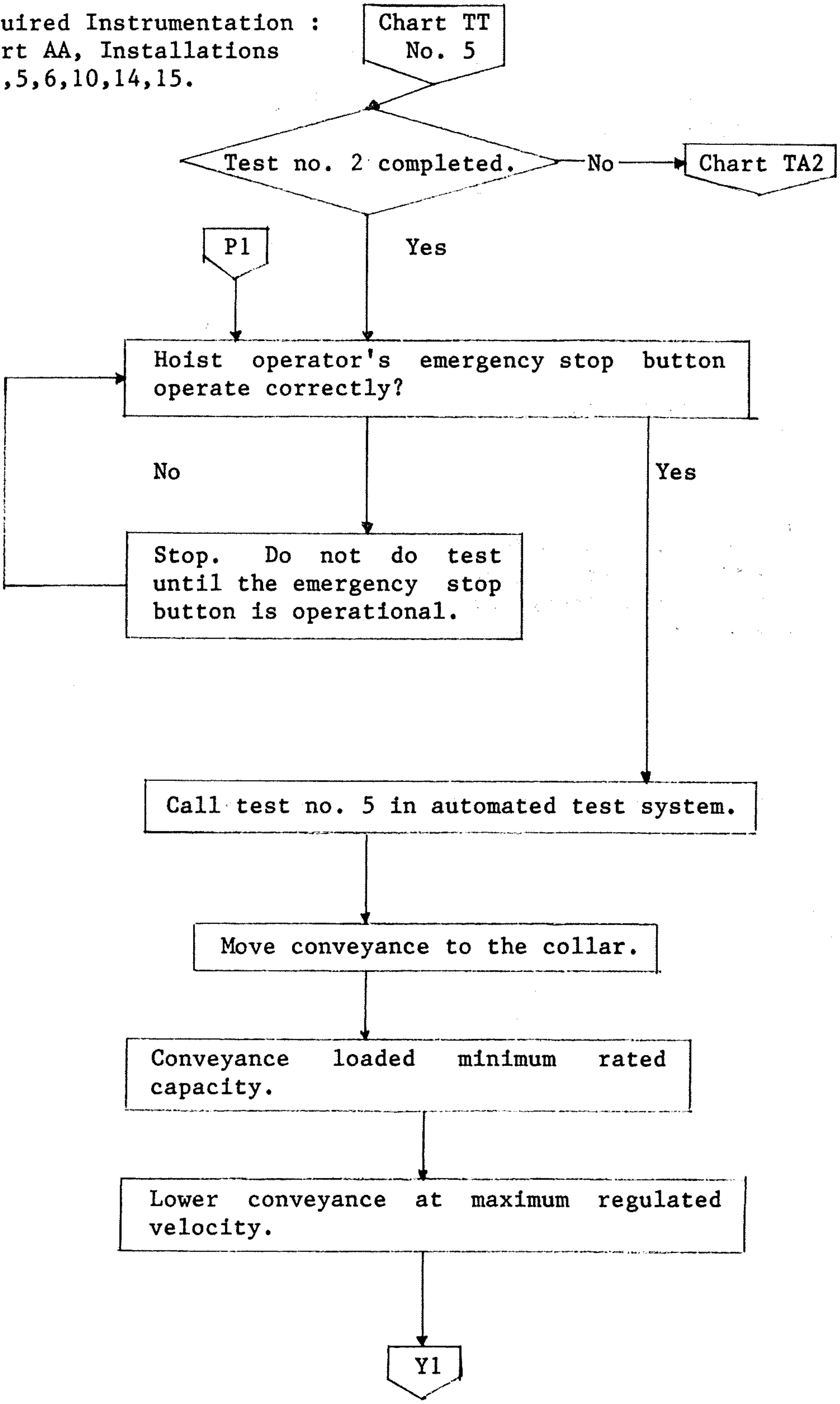
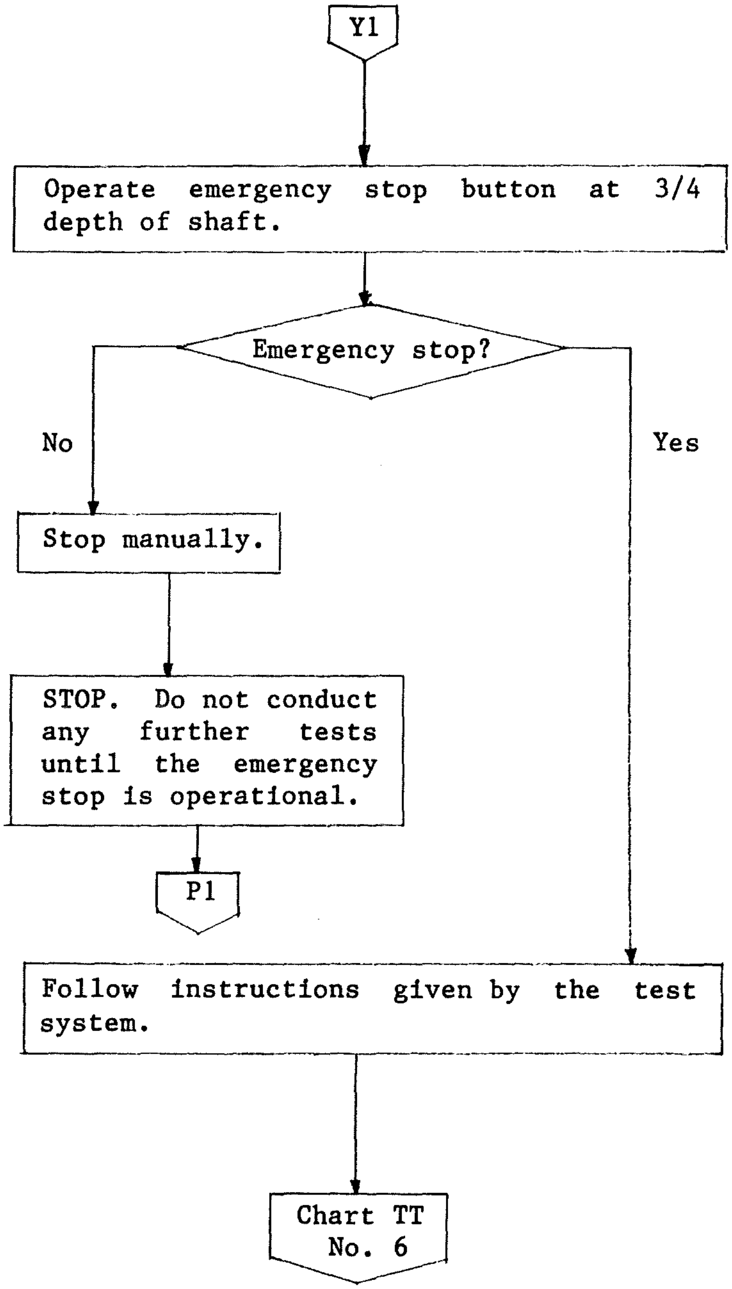


CHART TA5, continued.



TESTING
CHART TA6.

Test no. 6 - Overtravel and overtravel backout switch test. For undertravel only. - for overtravel see test 8.

Required instrumentation :
Chart AA. Installation
1,2,3,5,6,7,10,11,13,14.

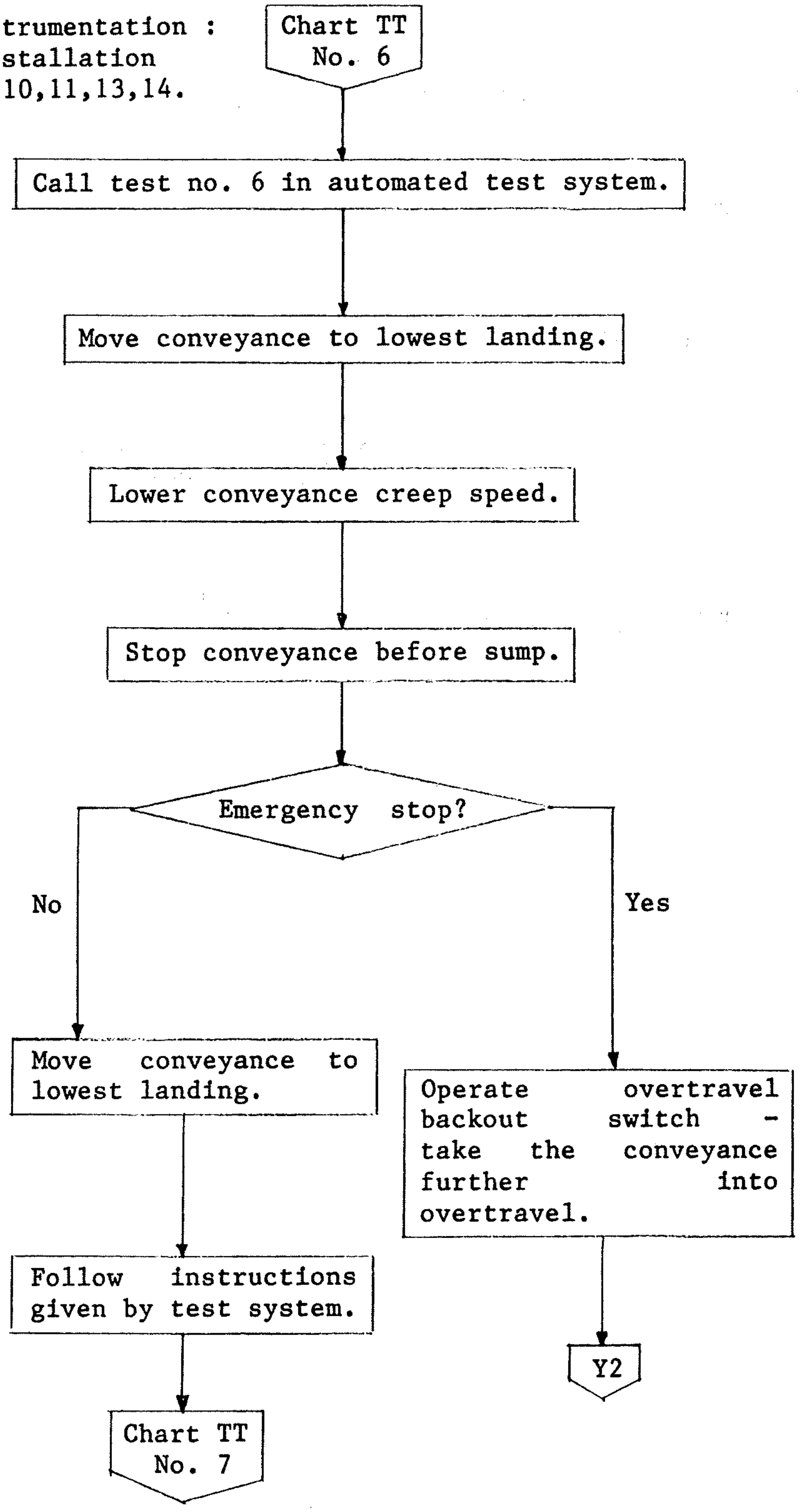
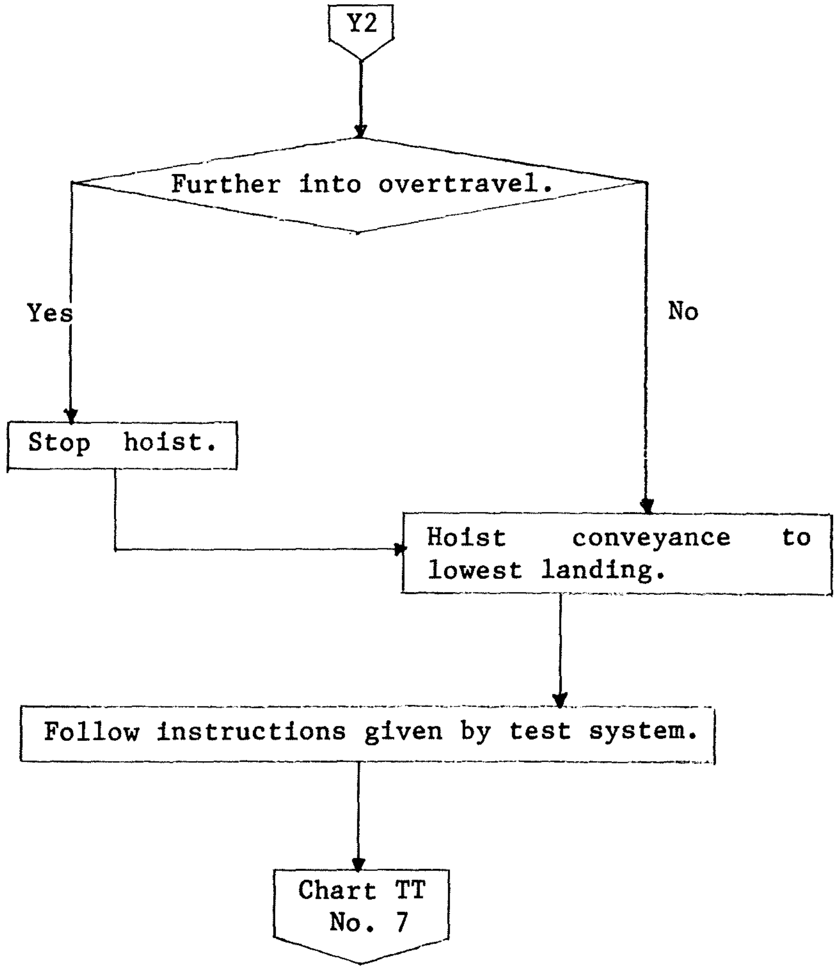


Chart TA6, continued.



TESTING
CHART TA7.

Test no. 7 : Third emergency stop test.

Required instrumentation :
Chart AA. Installations
1,2,5,6,10,14,15

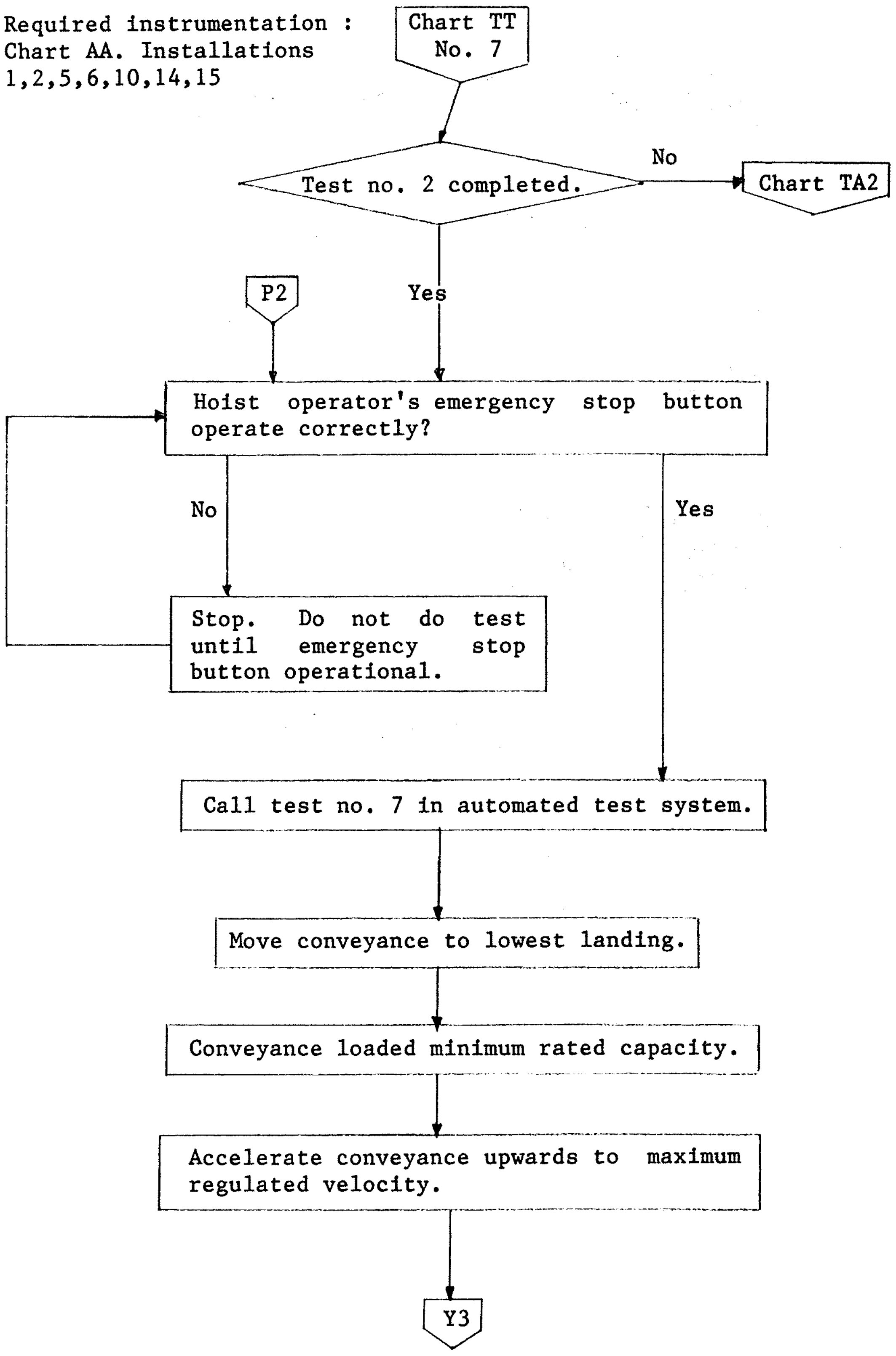
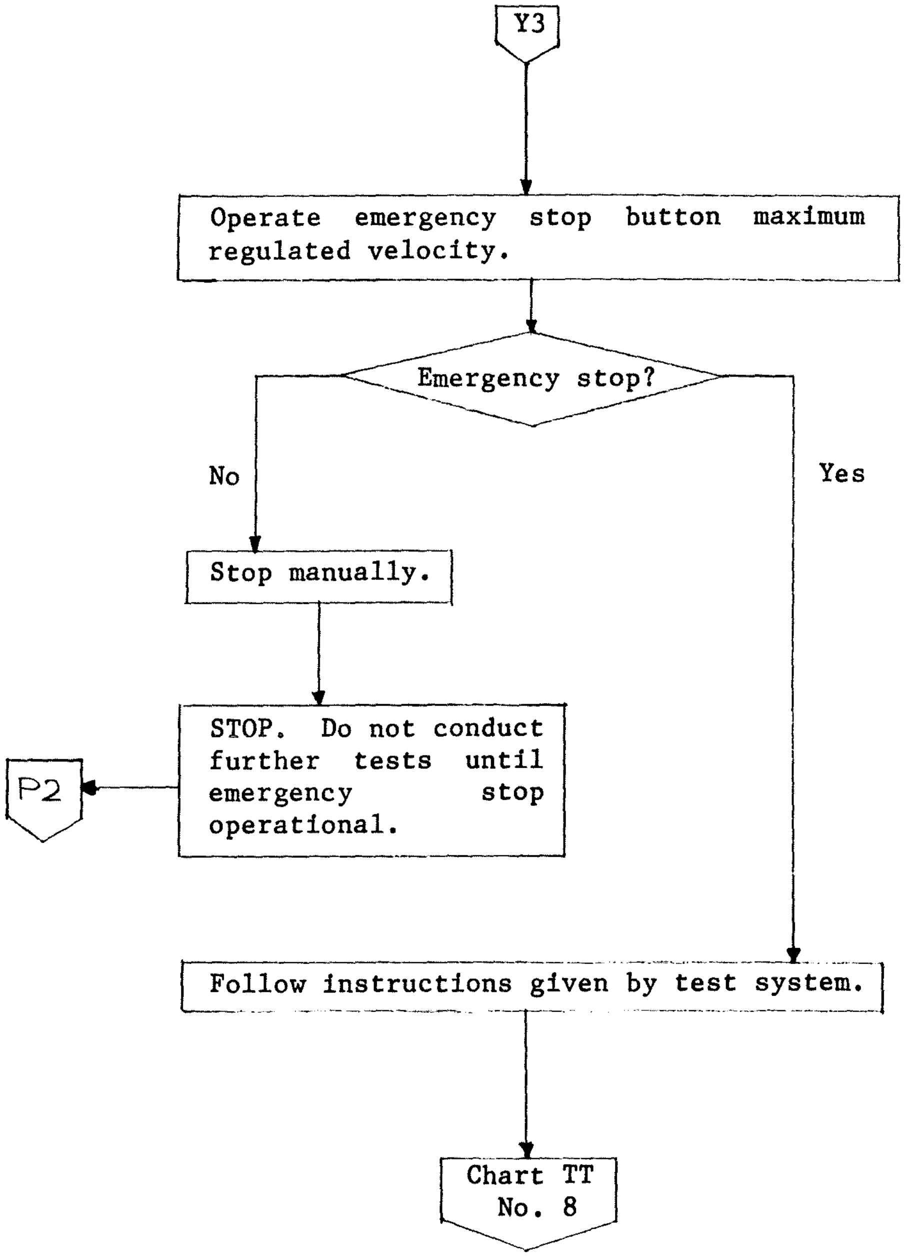


Chart TA7, continued.



TESTING
CHART TA8.

Test no. 8 : Overtravel and overtravel backout switch test. For overtravel only. - for undertravel see test 6.

Required instrumentation :
Chart AA. Installations
1,2,3,5,6,7,10,11,13,14.

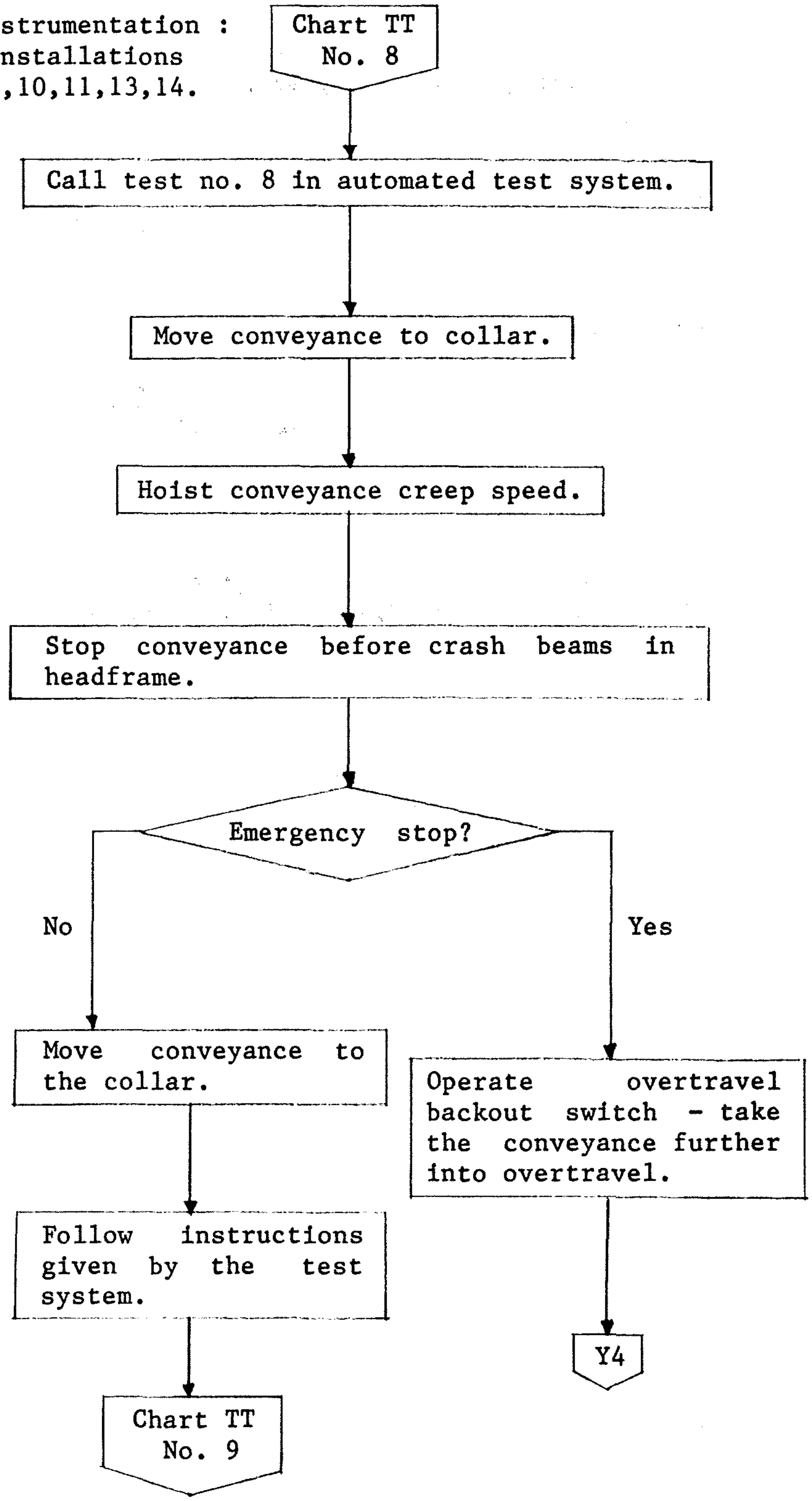
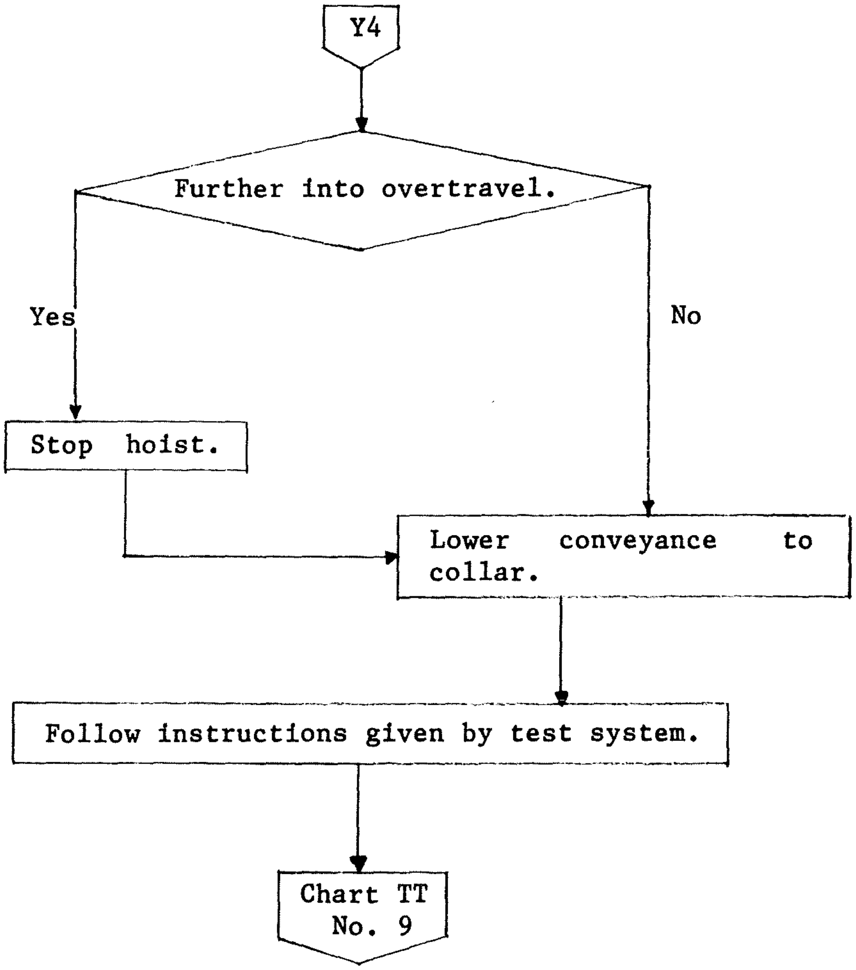


Chart TA8, continued.



TESTING
CHART TA9.

Test no. 9 : Fourth emergency stop test.

Required instrumentation :
Chart TT. Installations
1,2,5,6,10,14,15

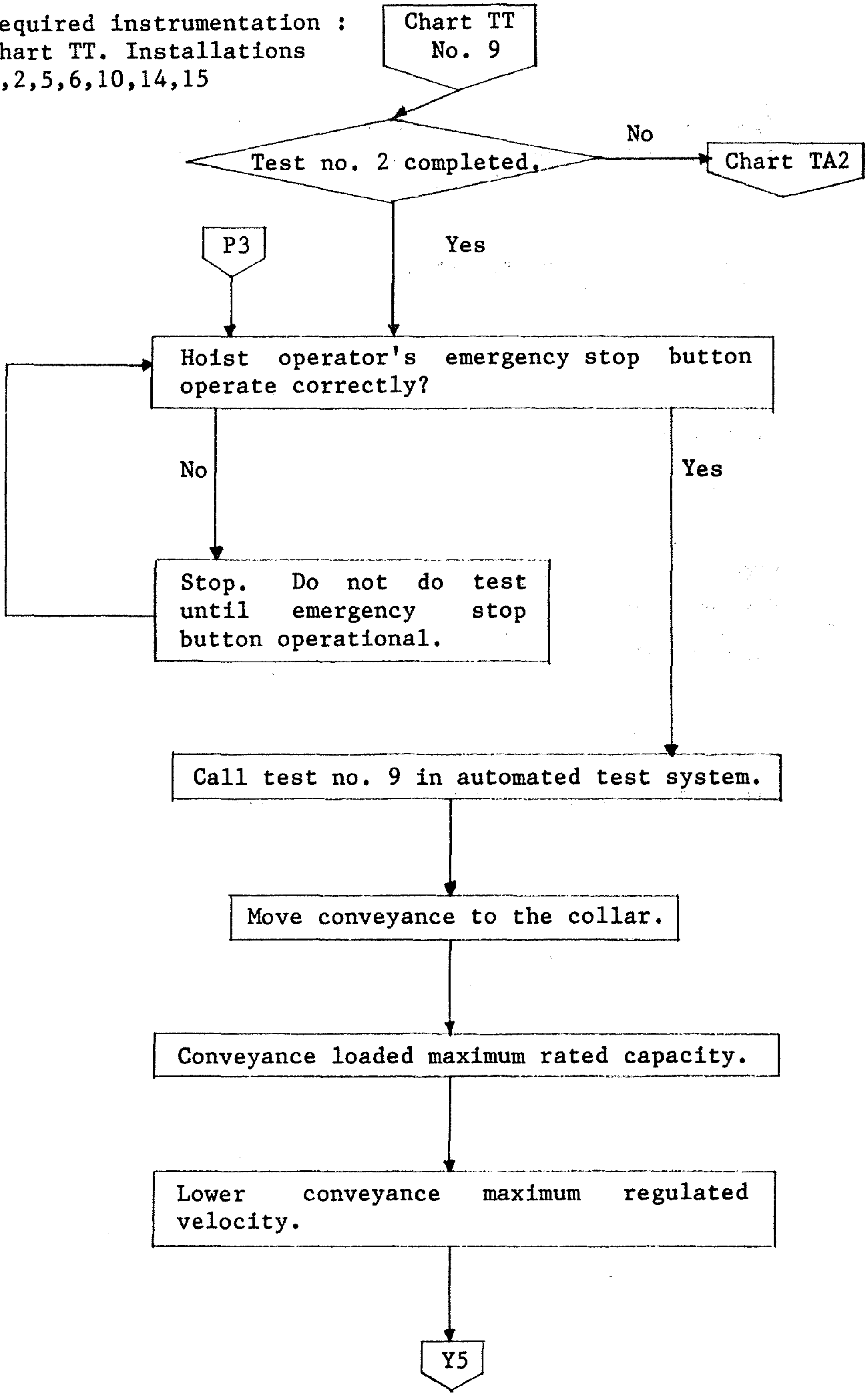
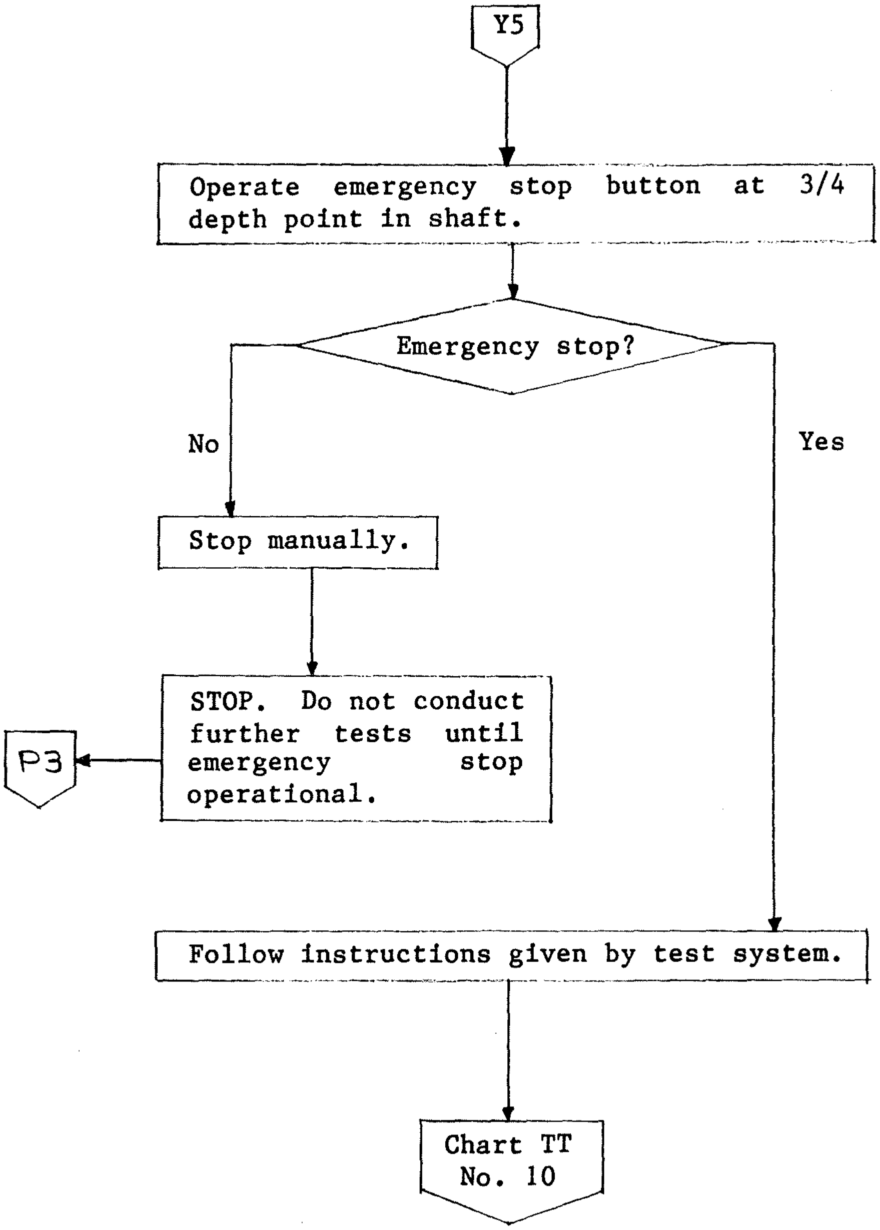


Chart TA9, continued.



TESTING
CHART TB1.

Test no. 10 - The "deadman" controller test.

Required instrumentation :
Chart AA. Installations
1,2,5,6,10,14.

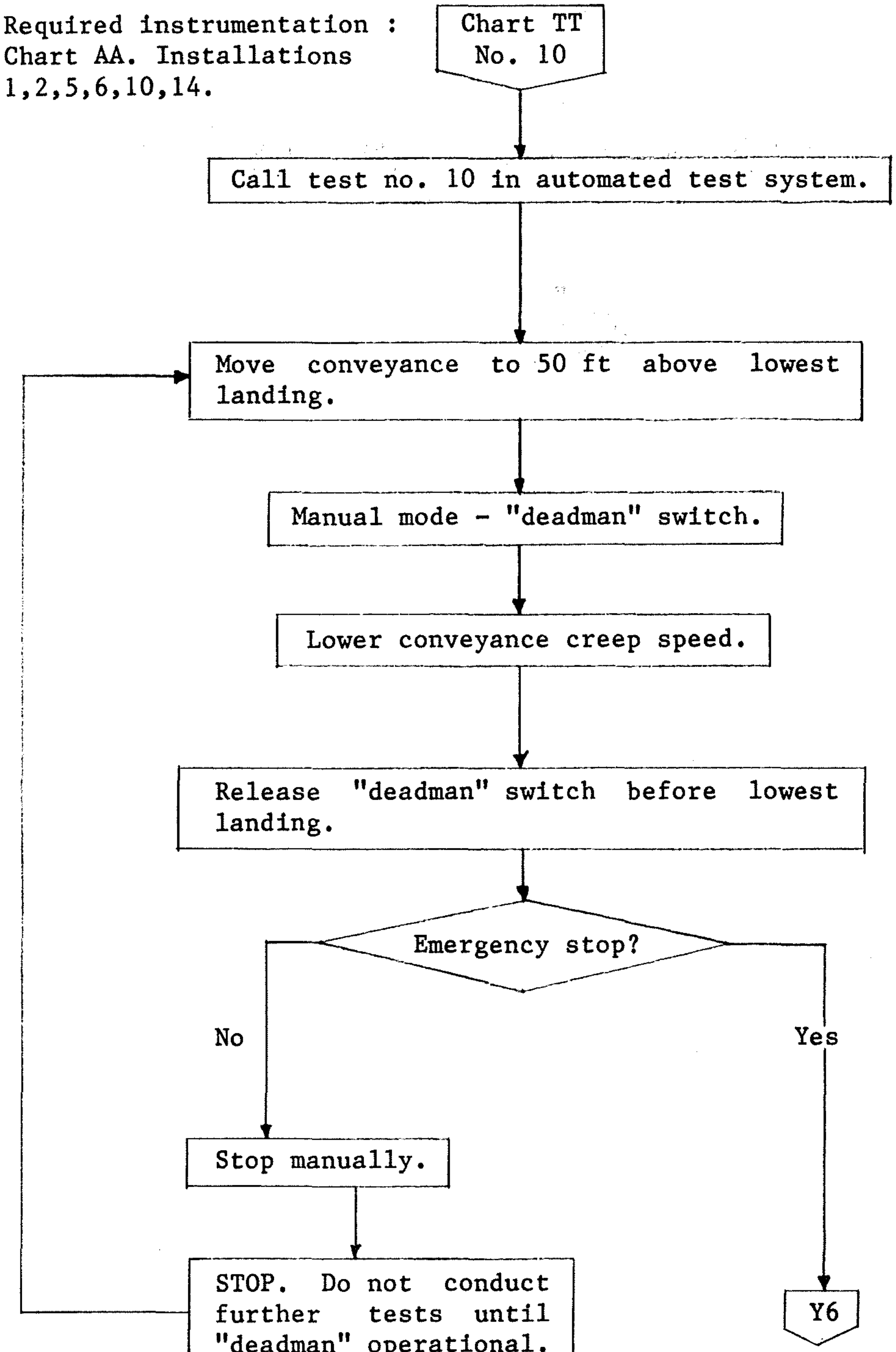
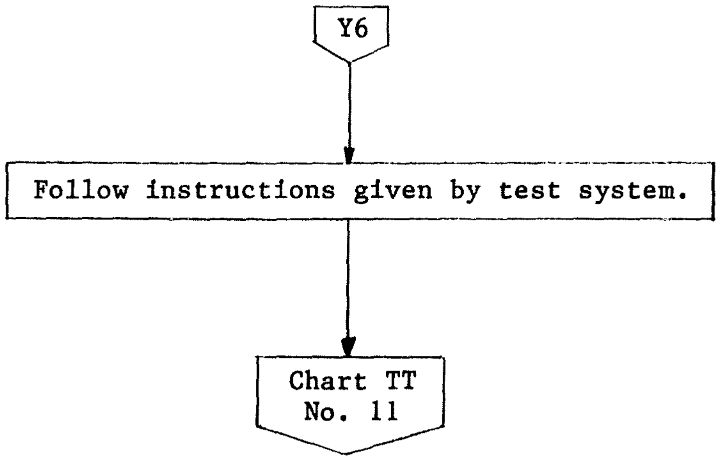


Chart TB1, continued.



TESTING
CHART TB2.

Test no. 11 : Last emergency stop test and overspeed test.

Required instrumentation :
Chart AA. Installations
1,2,5,6,10,13,14,15.

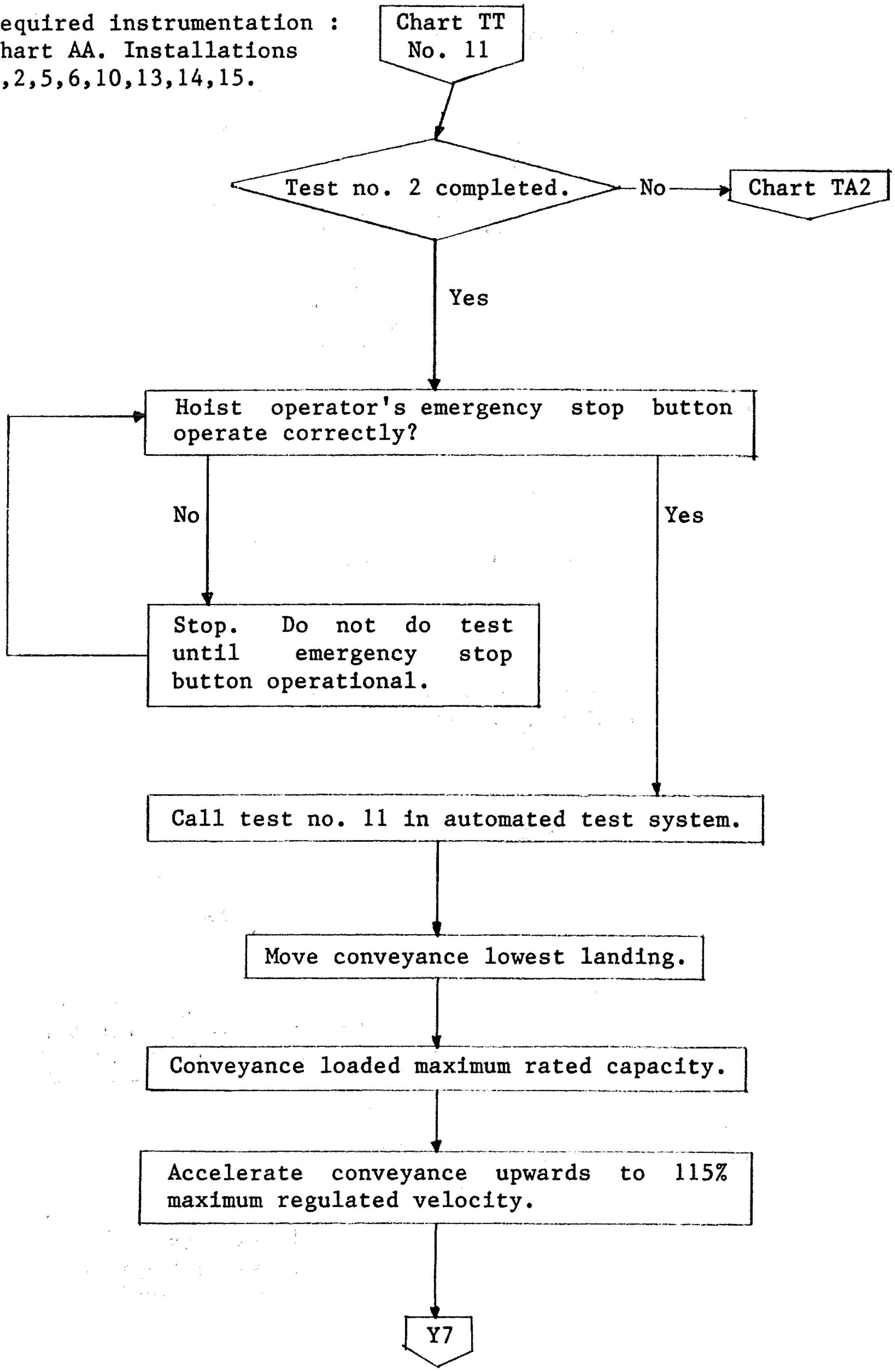
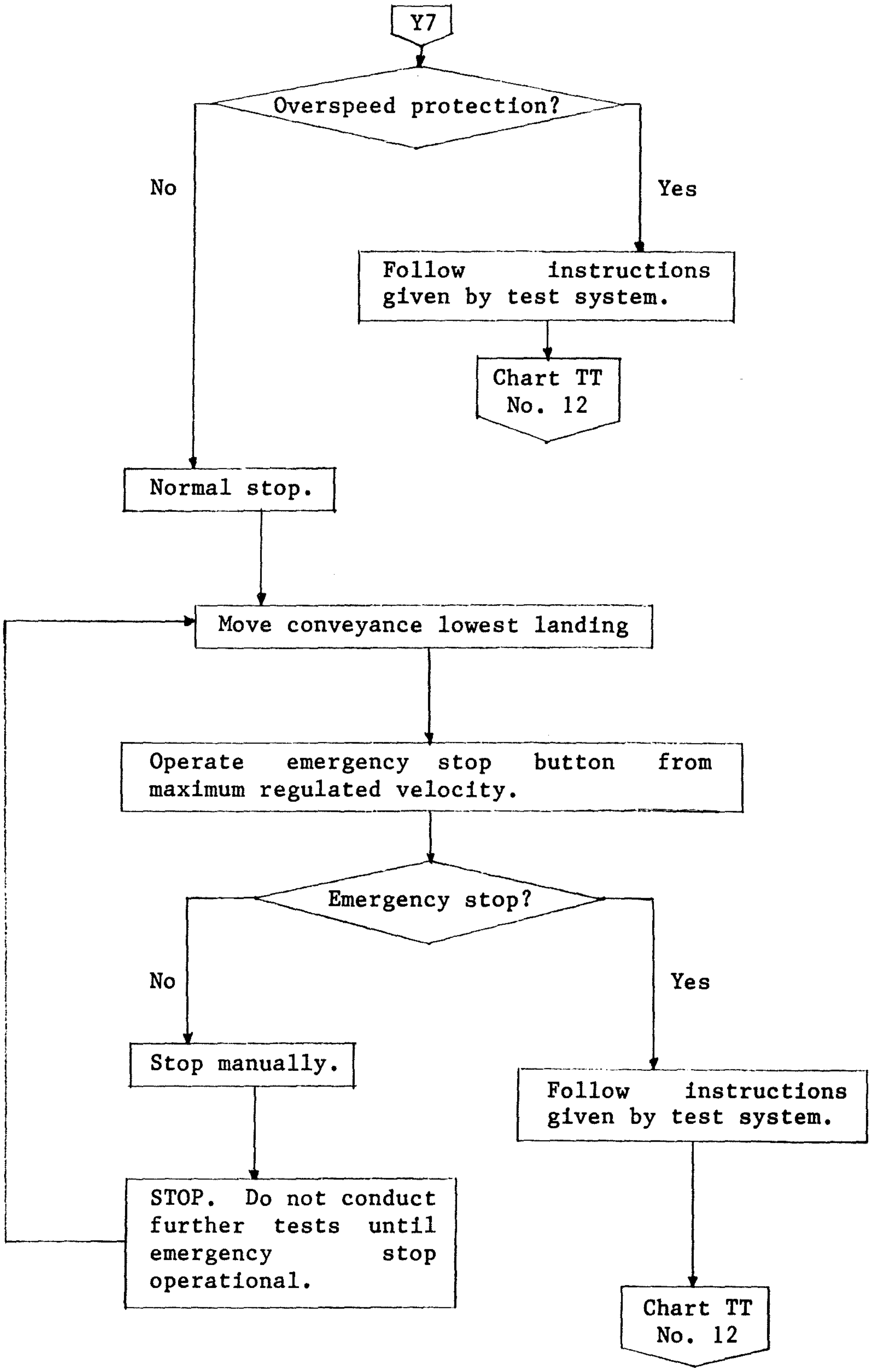


Chart TB2, continued.



TESTING
CHART TB3

Test no. 12 : Control power loss.

Required instrumentation :
Chart AA. Installations
1,2,4,5,9,10,14.

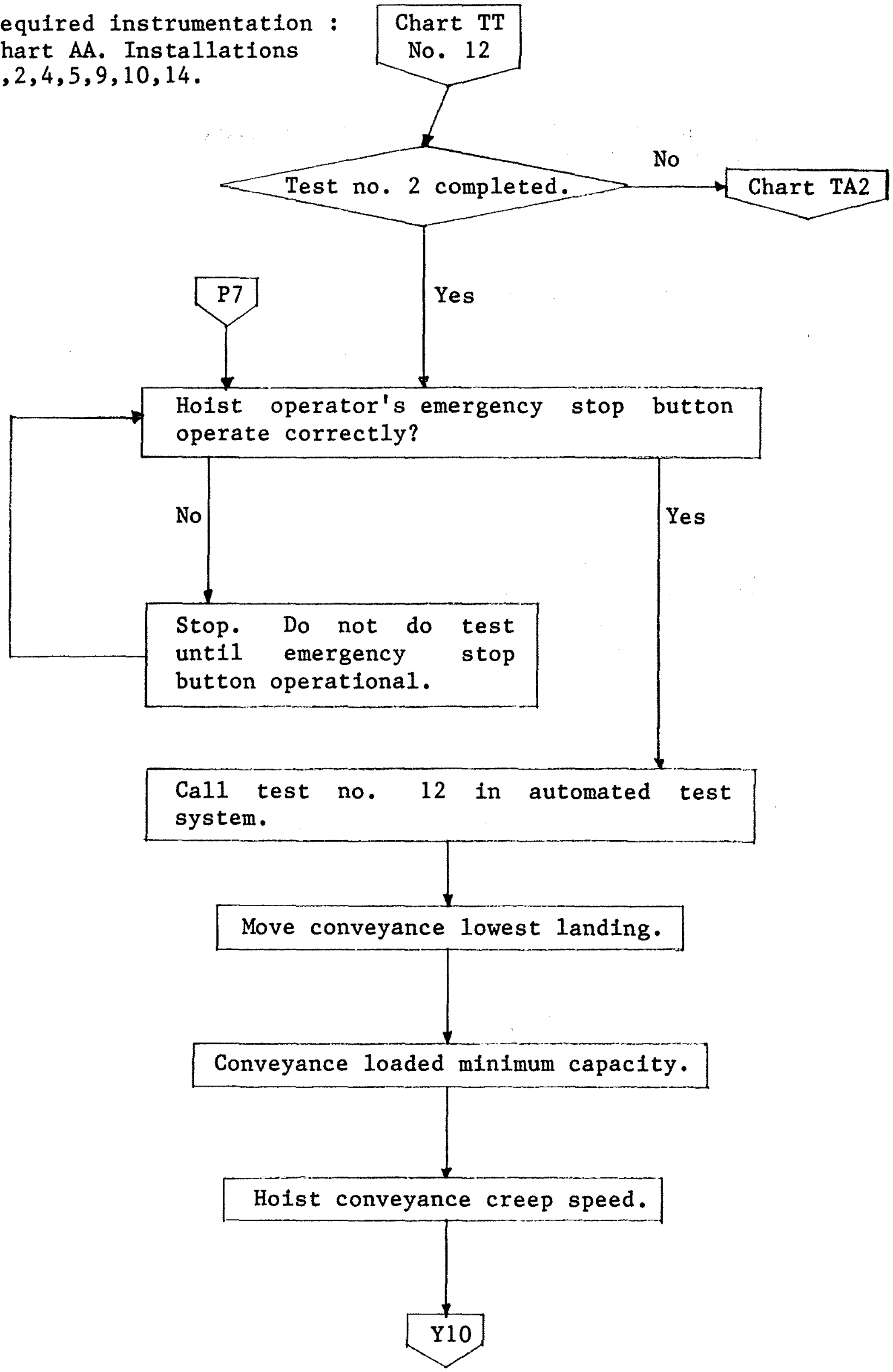
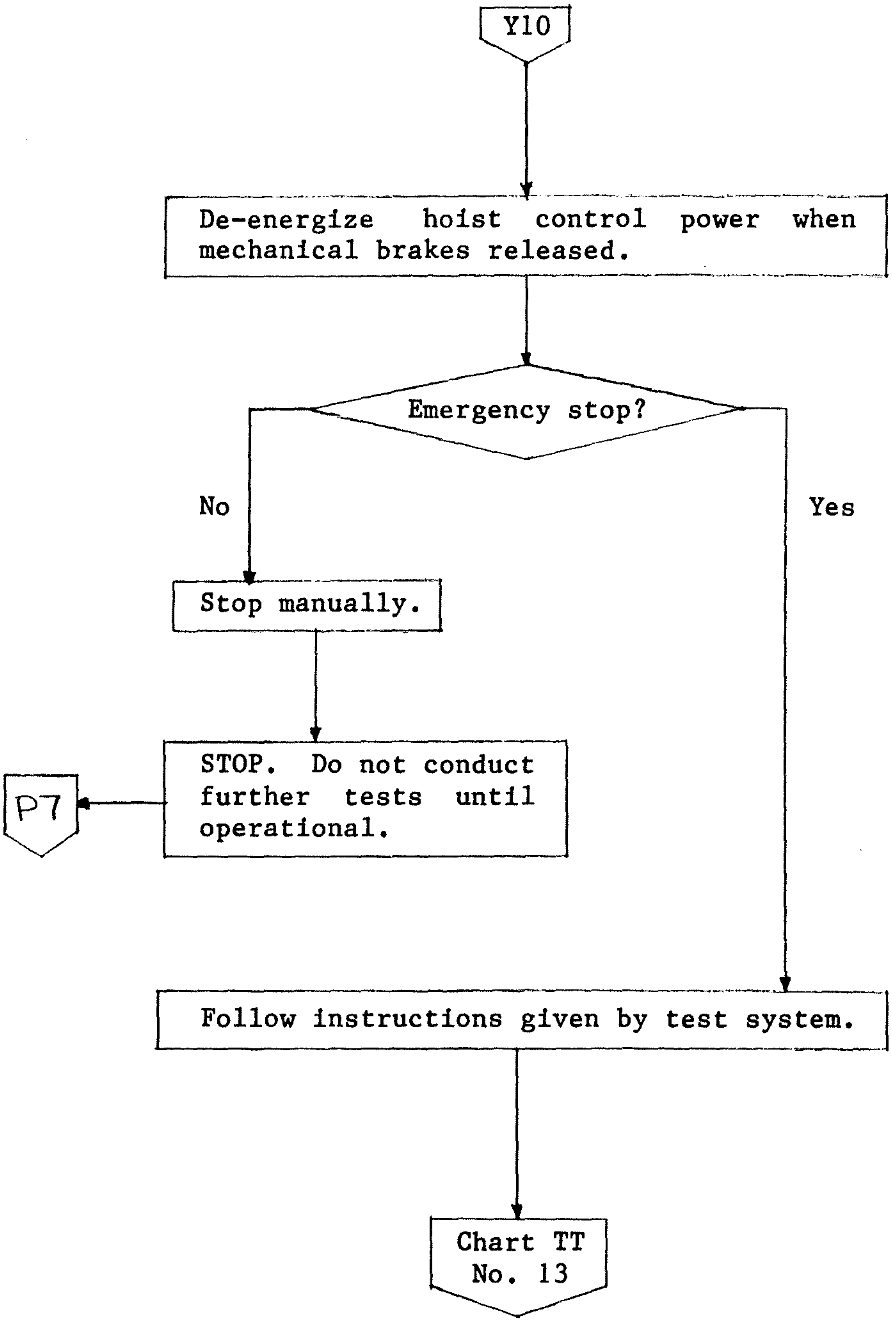


Chart TB3, continued.



TESTING
CHART TB4.

Test no. 13 : Hoist feeder power loss.

Required instrumentation :
Chart AA. Installations
1,2,4,5,8,10,14.

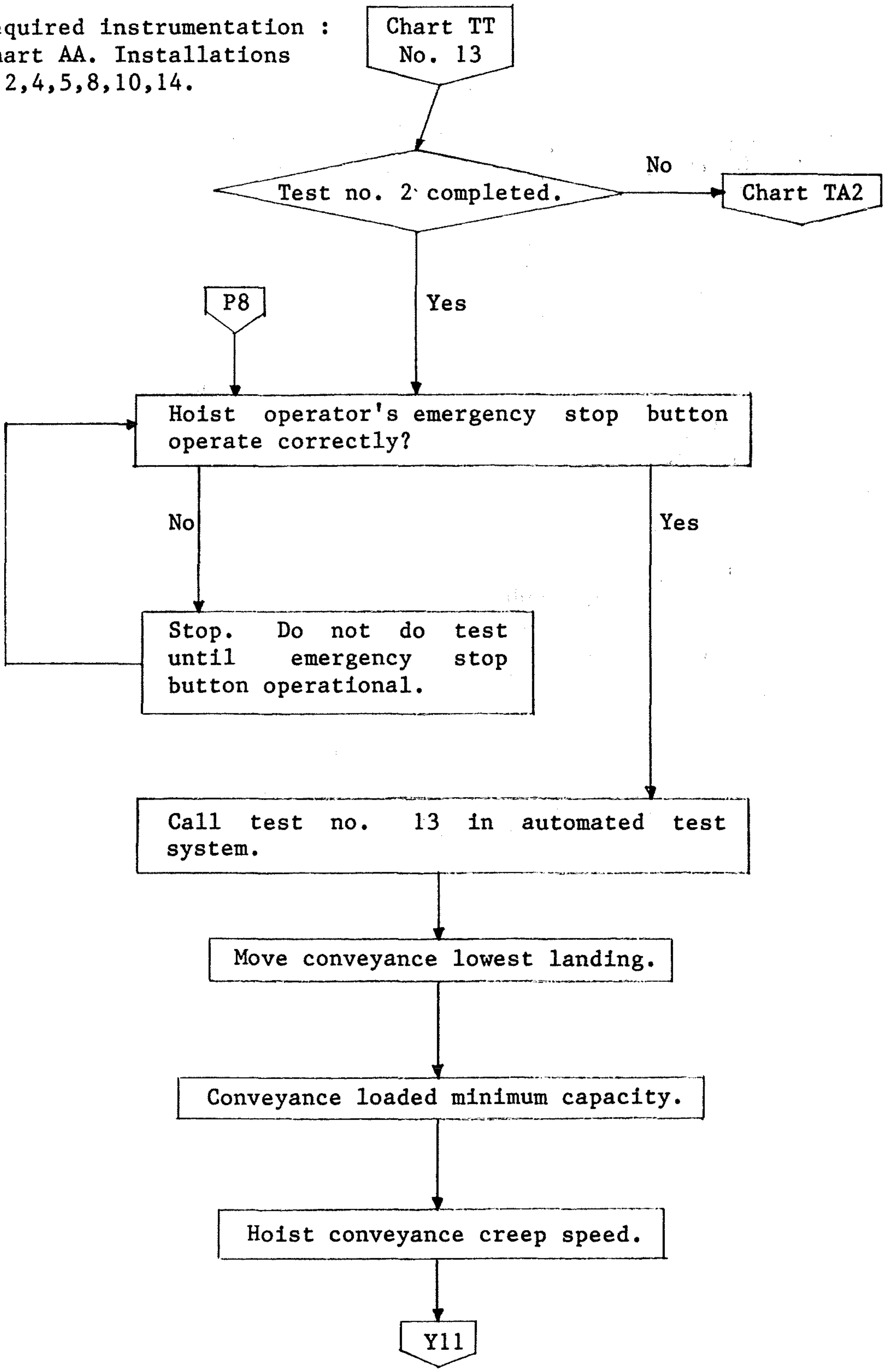
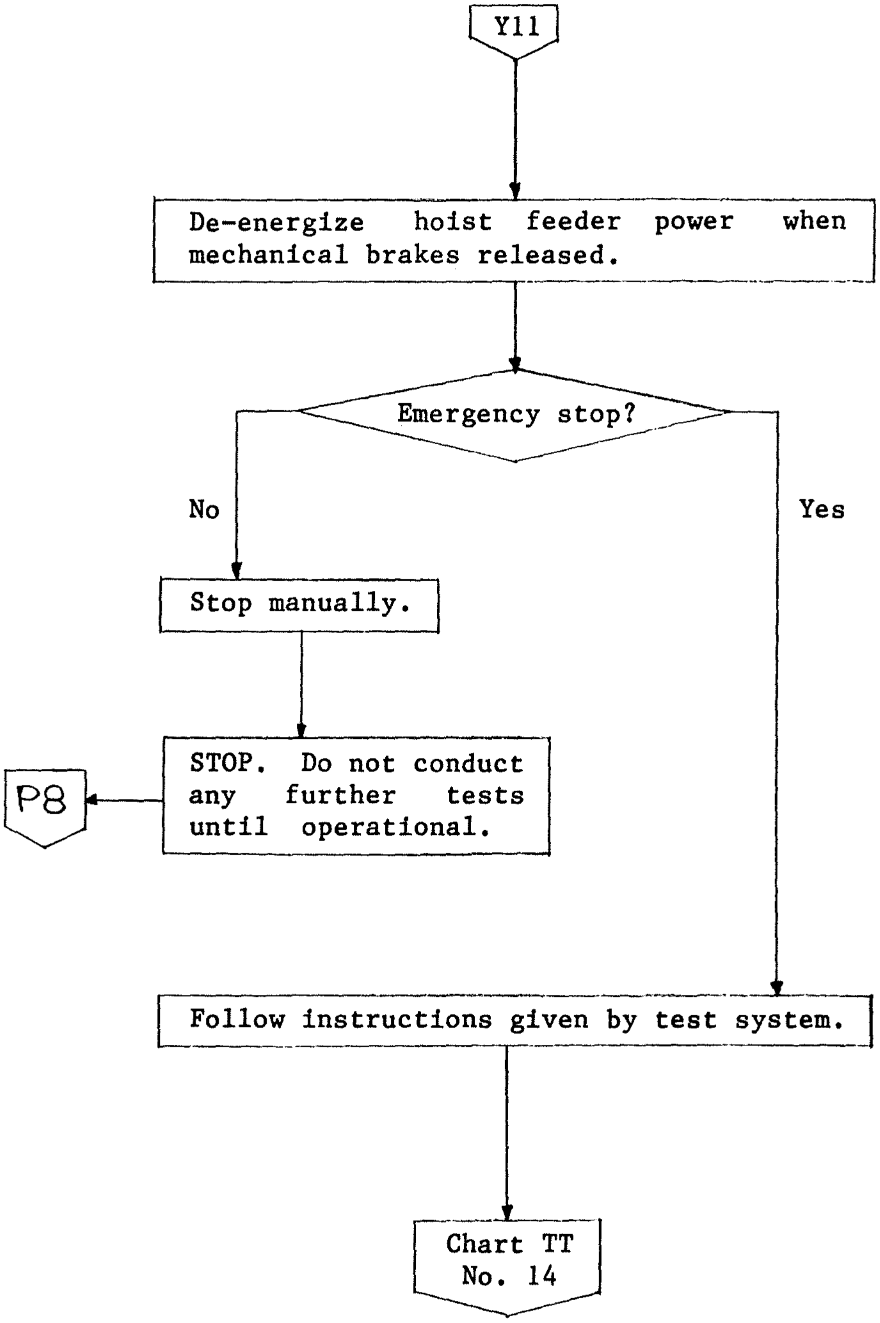


Chart TB4, continued.



TESTING
CHART TB5.

Test no. 14 : DC motor field loss.

Required instrumentation :
Chart AA. Installations
1,2,4,6,10,14.

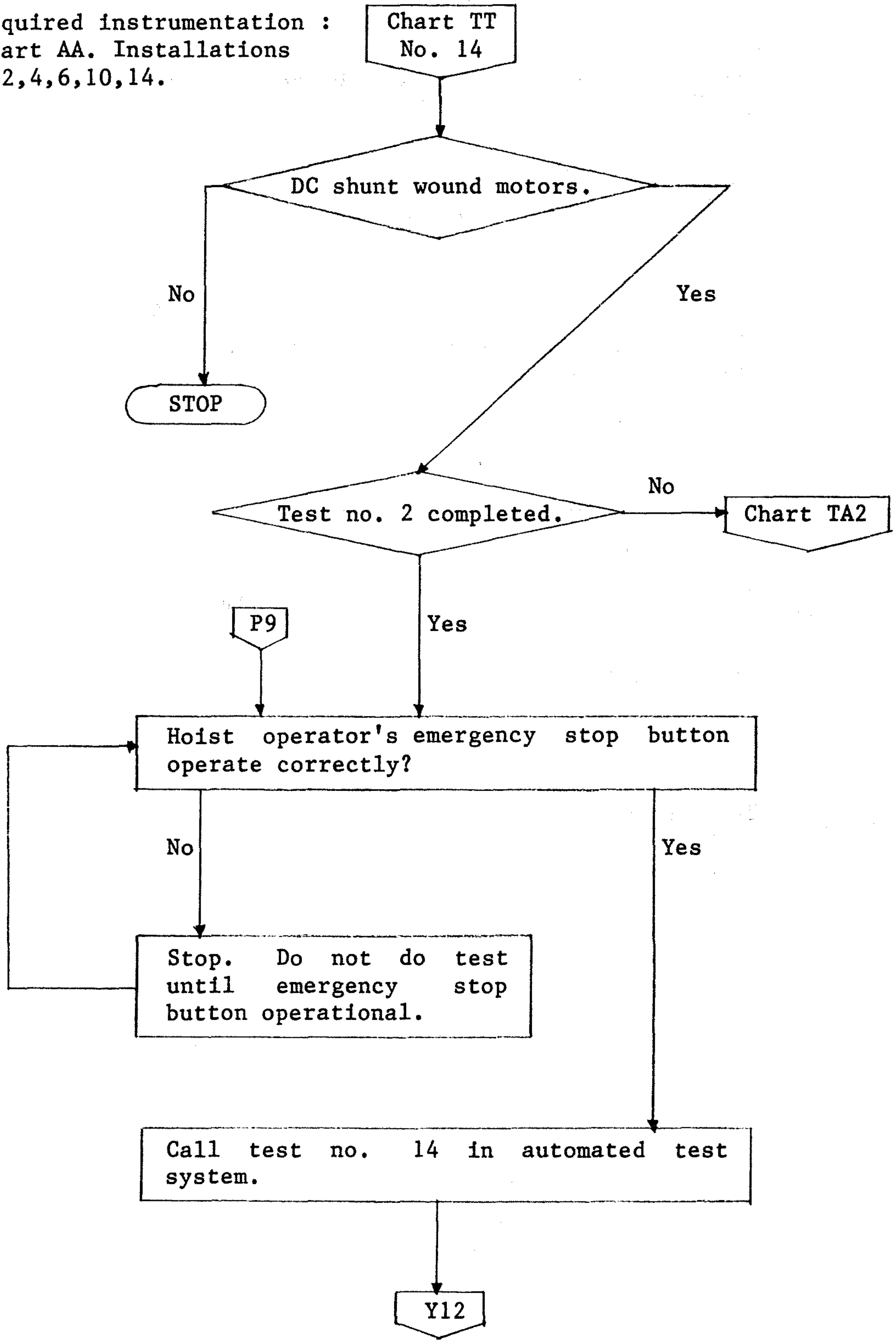


Chart TB5, continued.