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REPORT 1701

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DEPARTMENT OF THE NAVY
DAVID TAYLOR MODEL BASIN

THE DEVELOPMENT AND EVALUATION OF
THE TMB CABLE TENSION AND FOOTAGE
INDICATION SYSTEM

by

Denny F. Brown

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ABSTRACT

The operation and evaluation of a portable system designed to measure tension and footage payout remotely and continuously on a stationary or moving cable are presented. During tests of the system, accurate readings were obtained for static cable tensions up to 70,000 pounds, moving cable tensions up to 45,000 pounds, and cable payout speeds up to 70 feet per minute. Utilization of the system on sea trials has indicated that it is reliable and durable.

INTRODUCTION

The David Taylor Model Basin was requested¹ by the Bureau of Ships to develop a portable system to measure tension and footage payout, both remotely and continuously, on the 1.25-inch diameter cable used in the installation of the TOTO II deep-sea ship moor for Project AUTECH. In addition, the Model Basin was requested to construct two such units for use during the moor installation.

In previous mooring projects, cable tension and footage payout measurements were time consuming, inaccurate, and dangerous. Tension was measured with a load cell connected to the cable with a carpenter stopper. For each reading, it was necessary to stop the payout, attach the carpenter stopper and load cell to the cable, and then remove the two units to continue payout. Approximately one hour was required to complete this process. Footage payout measurements were obtained by painting marks on the cable at known intervals as it was being payed out and making a tally of these marks. The accuracy of this method was obviously limited. These methods were also hazardous since personnel were required to be in the vicinity of the cable while it was under high tension.

With due regard to the limitations of previous methods, the Model Basin designed and constructed two units of a new device, the TMB Cable Tension and Footage Indication System. This report presents the design and operation of the system and evaluates its performance on the basis of laboratory experiments and use during the AUTECH moor installation.

DESIGN REQUIREMENTS

The requirements for the new system¹ were deliberately made general to provide flexibility in the design. These requirements are listed below:

1. System to be used on 1.25-inch wire rope with a bituminous coating (for corrosion protection).

¹References are listed on page 23

2. Tension capacity to be about 100,000 pounds.
3. Capacity of the footage indicator to equal or exceed the length of wire rope on the storage winch (8,000 feet).
4. System to be used at cable payout rates up to 200 feet per minute.
5. Measurements to be read remotely and the tension readings to be recorded on a paper record.
6. Measurements to be continuous.
7. System to be portable to facilitate manual transfer between ships at sea.
8. Equipment to be reliable, durable, and capable of withstanding rough usage at sea.

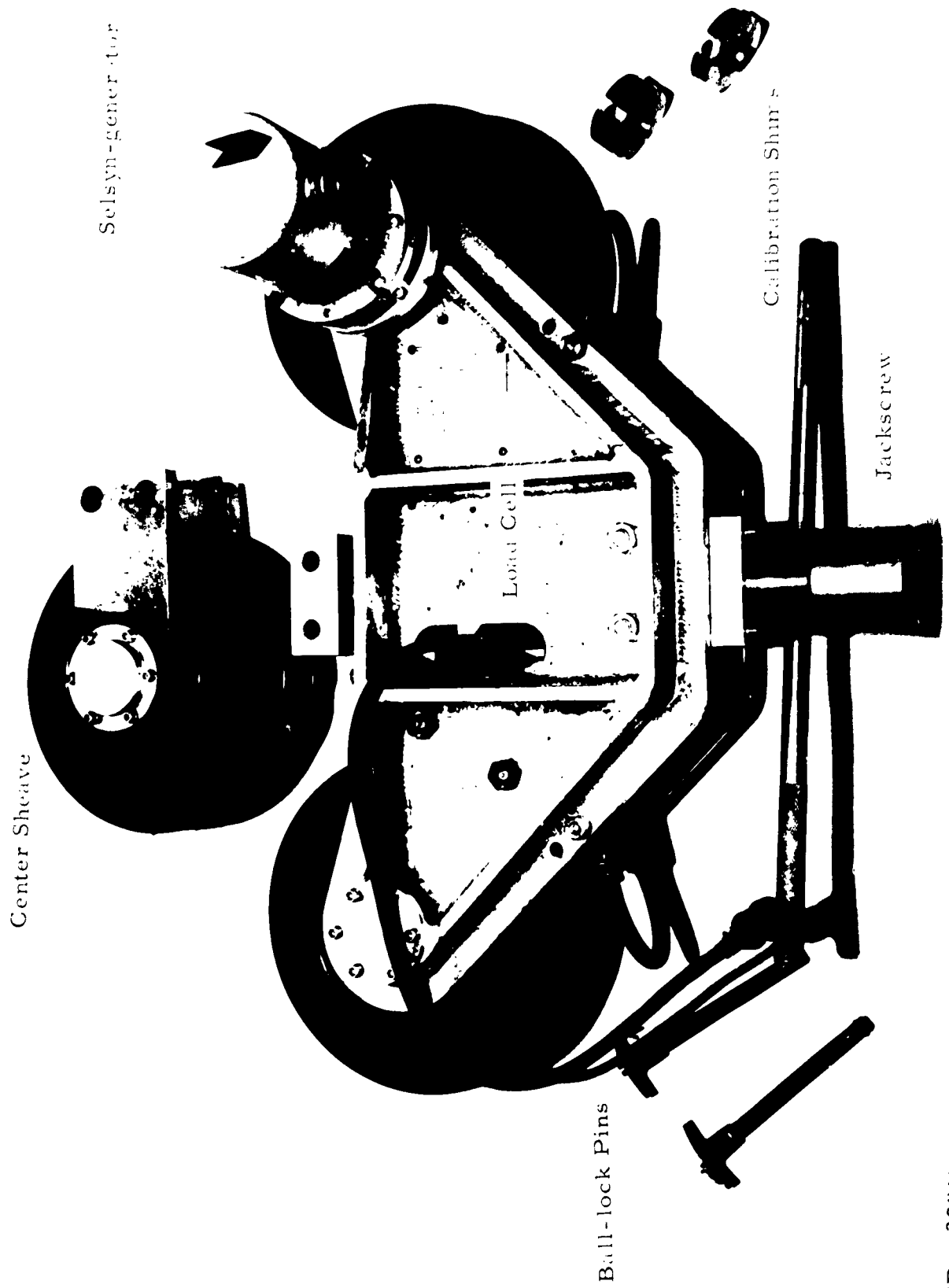
DESCRIPTION OF SYSTEM

The TMB Cable Tension and Footage Indication System is the designation given to the equipment which forms the subject of this report. An invention disclosure for the system has been filed with the Model Basin Patent Council². For clarity, the term "device" refers only to the unit that attaches to the cable and the term "system" refers to both the device and its associated recording equipment. The two systems which were constructed by the Model Basin are designated System A and System B. The only difference between the systems was that recorders of different manufacture were used to monitor tension since identical units were not available at the time of the installation.

DEVICE

Figure 1 shows the device partially disassembled and Figure 2 shows it installed on the cable during the TOTO II Moor operation. Basically, the device consists of three sheaves, a load cell, a jackscrew, a selsyn generator, and a supporting framework. The weight of the device is 160 pounds. The sheaves have a rolling circumference of 2 feet and are grooved to accept the 1.25-inch diameter mooring cable. The center sheave is detachable to permit installation or removal from the cable at any point. Ball-lock pins are used to facilitate the connection of this sheave to the rest of the device.

A 10,000-pound capacity Baldwin strain-type load cell is used to sense the cable tension. It is connected in series between the center sheave and the jackscrew. When the device is installed on the cable, the center sheave is deflected with the jack, causing a deflection in the cable. The force



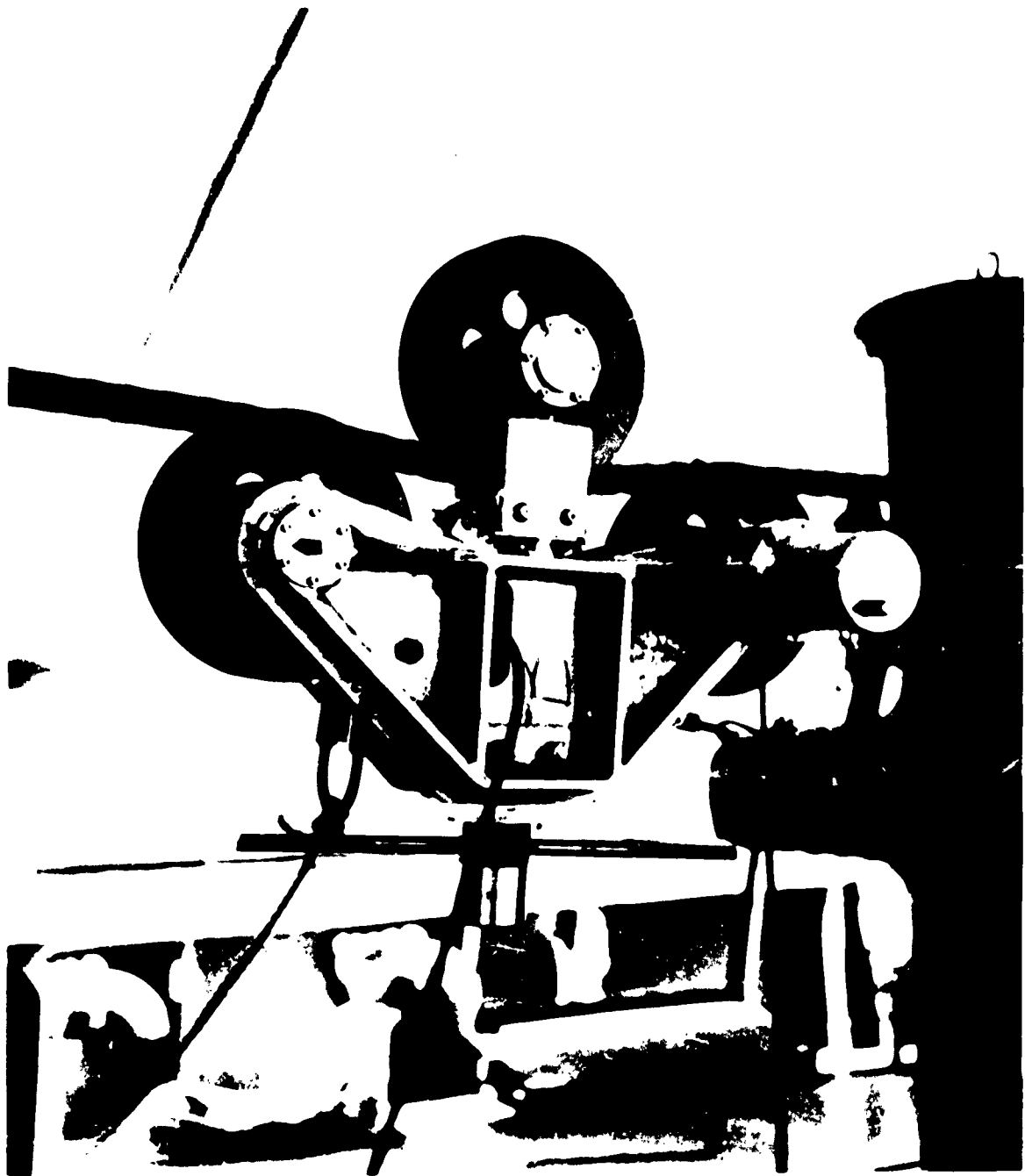


Figure 2 - Device Installed on Cable

exerted on the center sheave as a result of the deflection is measured with the load cell. This force is approximately proportional to the cable tension and is displayed on a recorder to indicate cable tension.

A ring shim, located between the load cell and base of the device, is used to govern the cable deflection and, consequently, the tension capacity of the device. Two shims were provided with each device, one for the "high tension range" (large shim) and the other for the "low tension range" (small shim). They are shown removed from the device in Figure 1.

A selsyn-generator motor set which drives a mechanical counter is used to indicate footage payout directly. The selsyn-generator is gear driven by the sheave and is housed in the cylindrical container shown in Figure 1. Both selsyn-generator and selsyn-motor are powered by a 60-cycle per second, single-phase 110-volt power source.

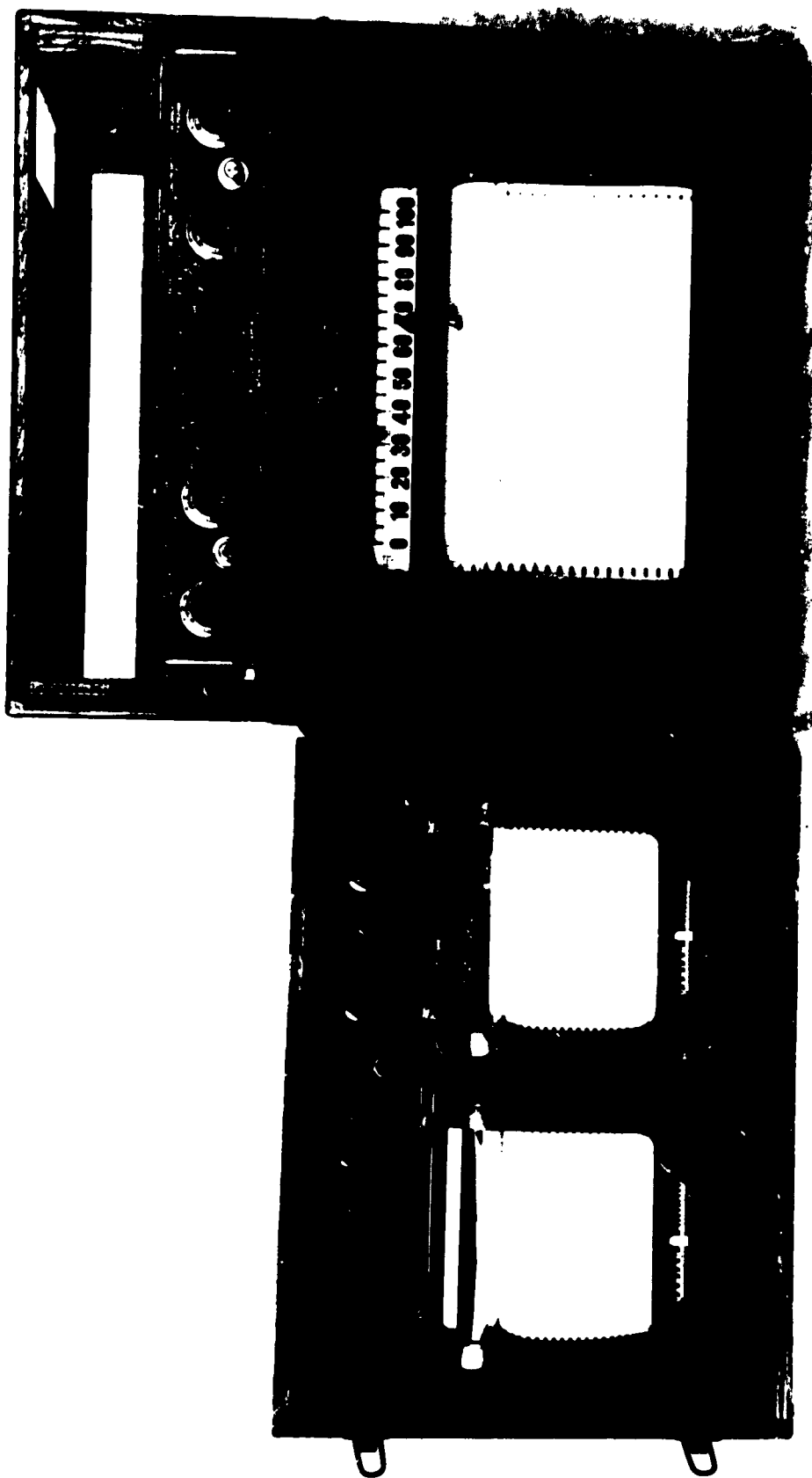
RECORDING INSTRUMENTS

The tension recorders for both systems are shown in Figure 3. The Brown Recorder was used with System A and the Varian Recorder was used with System B. The Brown Recorder is more accurate and has a greater sensitivity; the Varian is lighter and easier to handle.

The footage-counter instrumentation, containing the selsyn-motor and counter, is shown in Figure 4. The counter is a 5-digit mechanical unit which can indicate numbers up to 100,000. The displayed number increases or decreases depending on the direction of motion of the cable. A knob on the counter is used to reset the footage indication. The gears between the motor and counter permit the cable length to be read directly in feet.

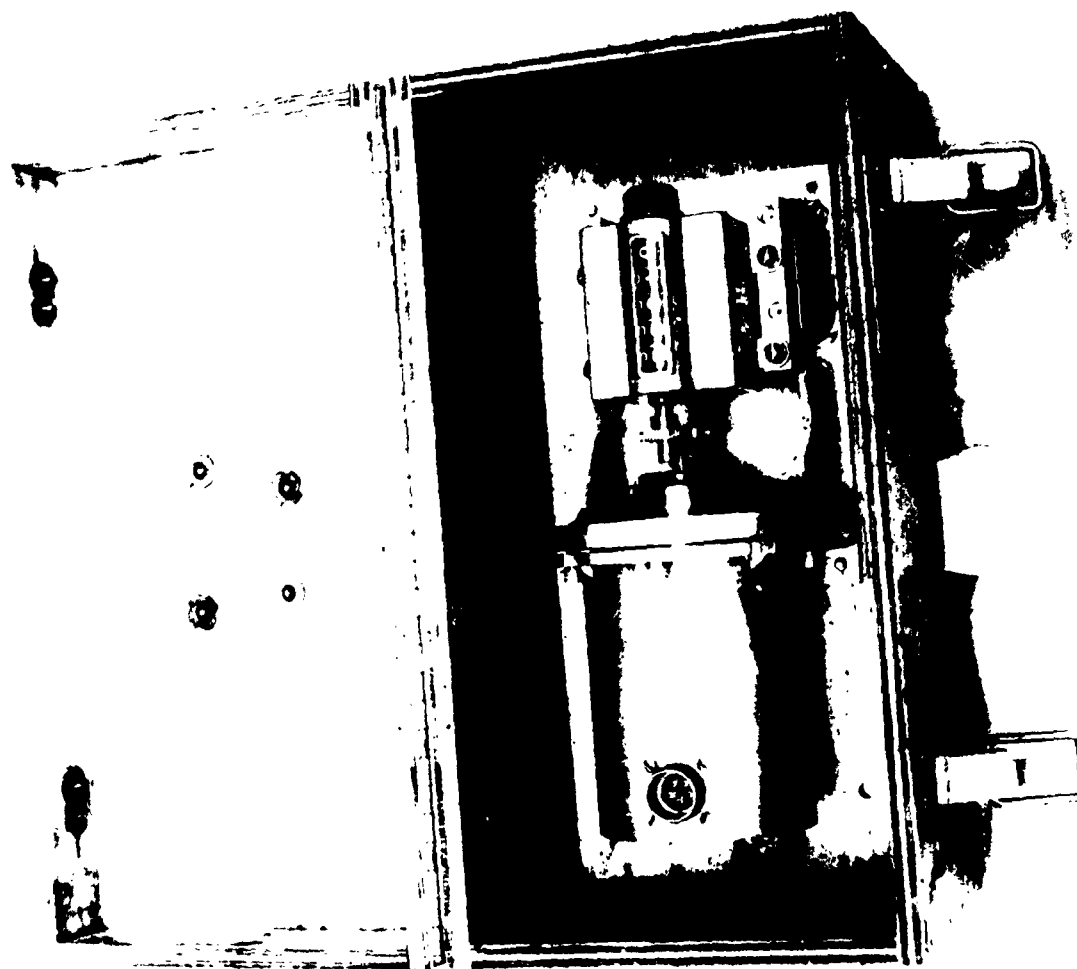
CALIBRATION OF SYSTEM

The systems were statically calibrated for tension in the 120,000 and 600,000-pound capacity test machines at the Model Basin. It should be pointed out that these test machines are provided with multiple scales for different force ranges and that the titles refer to the capacity of the highest range scale. Initially, a direct calibration was made on the 10,000-pound Baldwin load cell in the 120,000-pound capacity test machine (scale range-24,000 pounds), as shown in Figure 5a. The device was then installed on a 15-foot length of the mooring cable in the 600,000-pound test machine (scale range 150,000 pounds), as shown in Figure 5b. Using the Baldwin load-cell calibrations, the cable tension capacity of the devices with each shim was determined by noting the tension required to exert a force of 10,000 pounds on the load cell. The capacity was found to be approximately 100,000 pounds with the large shim and approximately 60,000 pounds with the small shim. The systems were calibrated for several tension ranges but the maximum cable tension was limited to 70,000 pounds to prevent possible damage to the calibration cable (yield 90,000 pounds).



PSD 308160

Figure 3 - Tension Recorders



PSD-308157

Figure 4 - Footage Counter

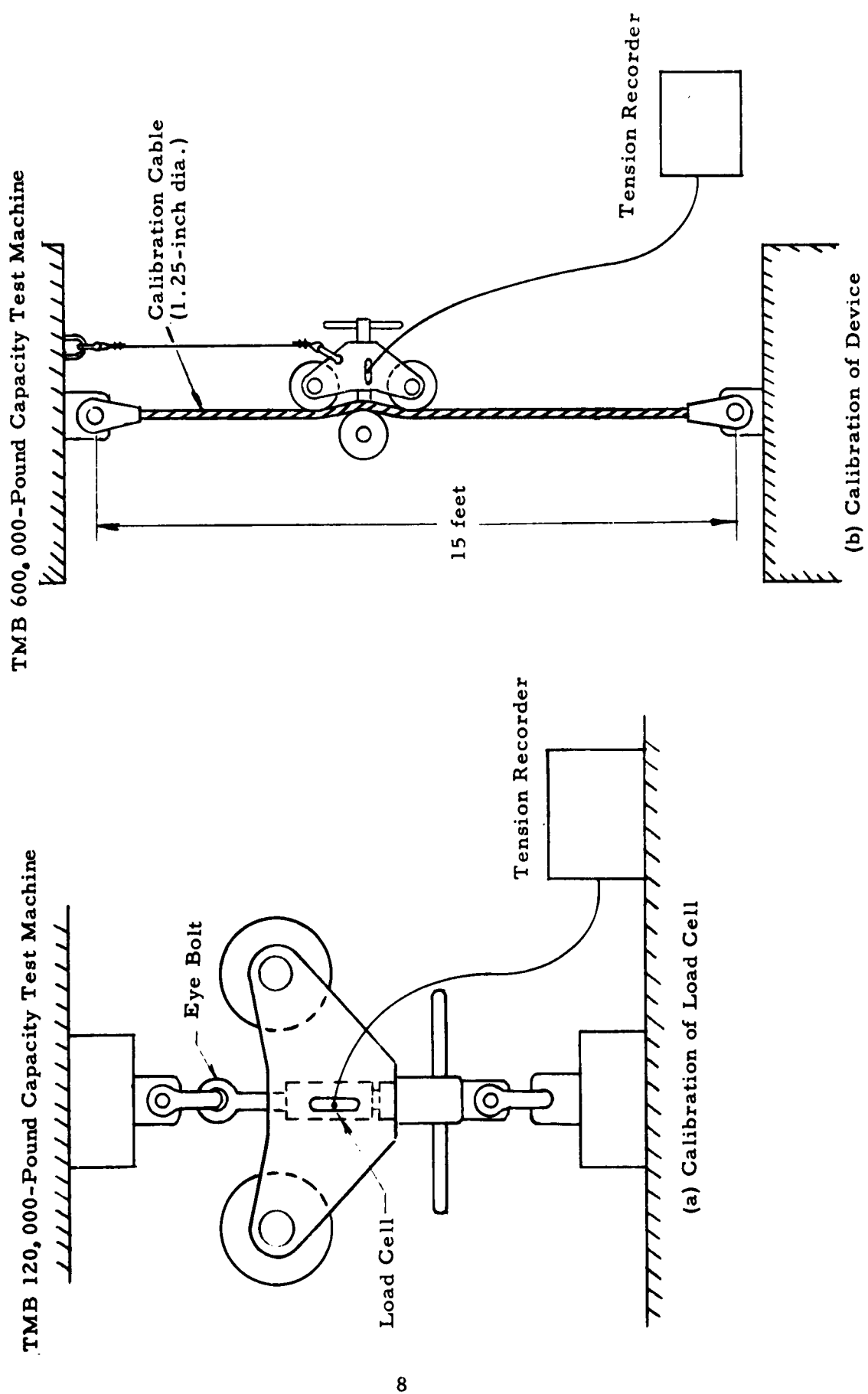


Figure 5 - Schematic of Tension Calibration in Test Machines

Figures 6 and 7 show the static tension calibration curves for System A and B, respectively. The calibrations are not linear because of a change in effective cable angle with tension. Figure 6 contains two calibration curves for each of the two shims. The middle curve was constructed by adjusting the recorder to read full scale for a tension of 50,000 pounds. It is interesting to note that, in this case, the calibration data for the two shims describe a single curve over the entire range of tension values.

Because of cable stiffness, forces of 400 and 600 pounds are exerted on the load cell with the large and small shim, respectively, for zero tension along the neutral axis of the cable. When the device is to be installed on a cable under tension, these forces must be taken into account in setting the recorder zero.

Figures 8 and 9 show the effective cable angles for both systems as a function of cable tension. The effective angle θ imposed on the cable by the device is given by

$$\theta = \sin^{-1} \frac{F_y}{2T}$$

where

F_y is the force exerted on the load cell, and

T is the cable tension.

As expected, the angle is reduced as the cable tension is increased due to "necking-down" of the cable and elongation of the load cell. However, the magnitude of the angle indicates that the device should not damage the cable. The difference in the effective angles for the two devices is due to manufacturing tolerances in their construction.

PROOF TESTS OF SYSTEM

A facility at the Bell Telephone Laboratories, Chester, New Jersey, was used to test the devices on a moving length of the mooring cable since this type of facility was not available at the Model Basin. These tests were conducted to determine whether the static calibrations were directly applicable to a moving cable and to determine the accuracy of the footage indicator under simulated operating conditions.

TEST APPARATUS

The Bell facility, shown in Figure 10, consists of two drums, 10 and 7 feet in diameter with their axles located 100 feet apart. The smaller drum is power driven and is capable of rotating at variable speeds in either direction to a maximum tangential velocity of 70 feet per minute. This

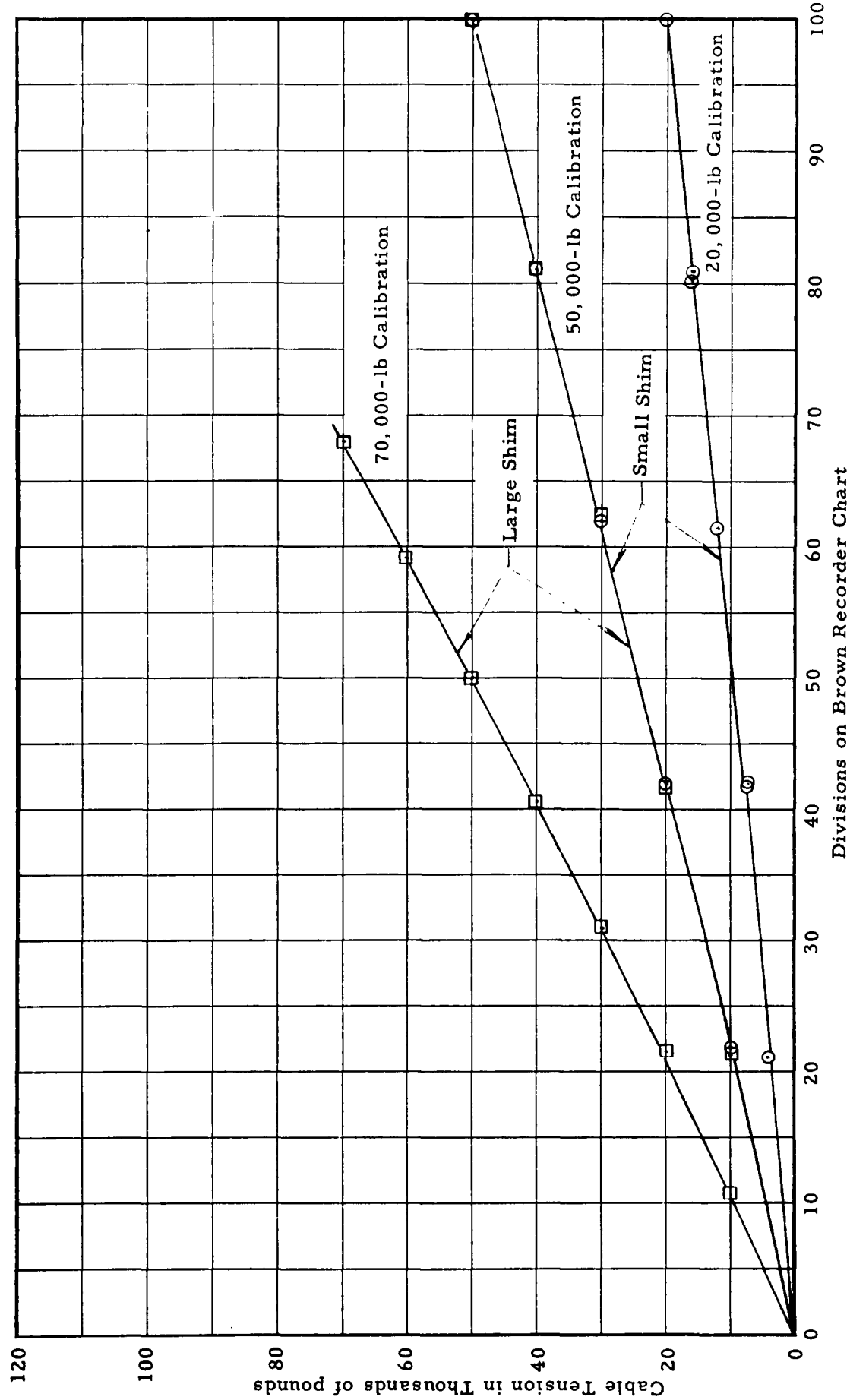


Figure 6 - Static Tension Calibration Curves for System A

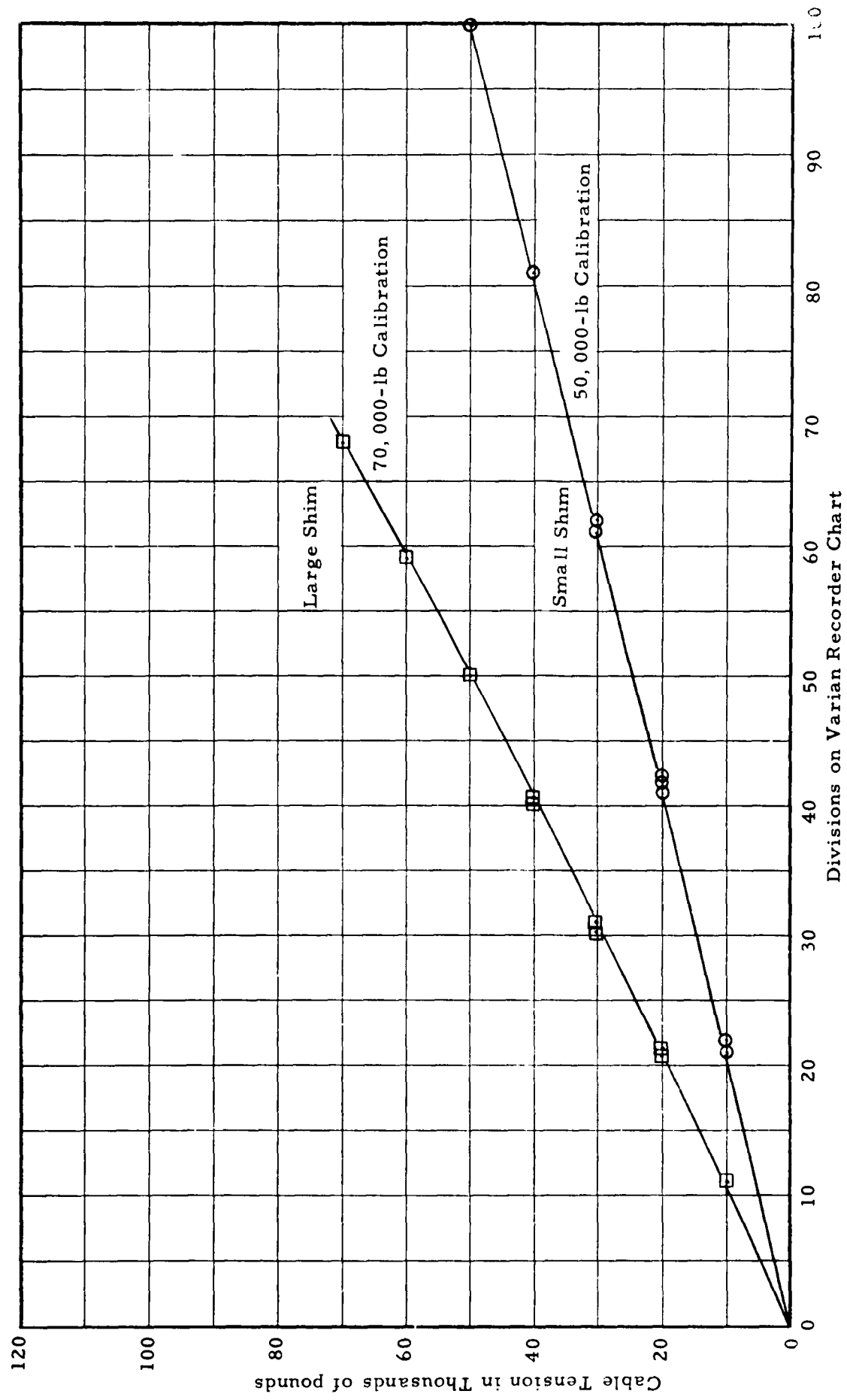


Figure 7 - Static Tension Calibration Curves for System B

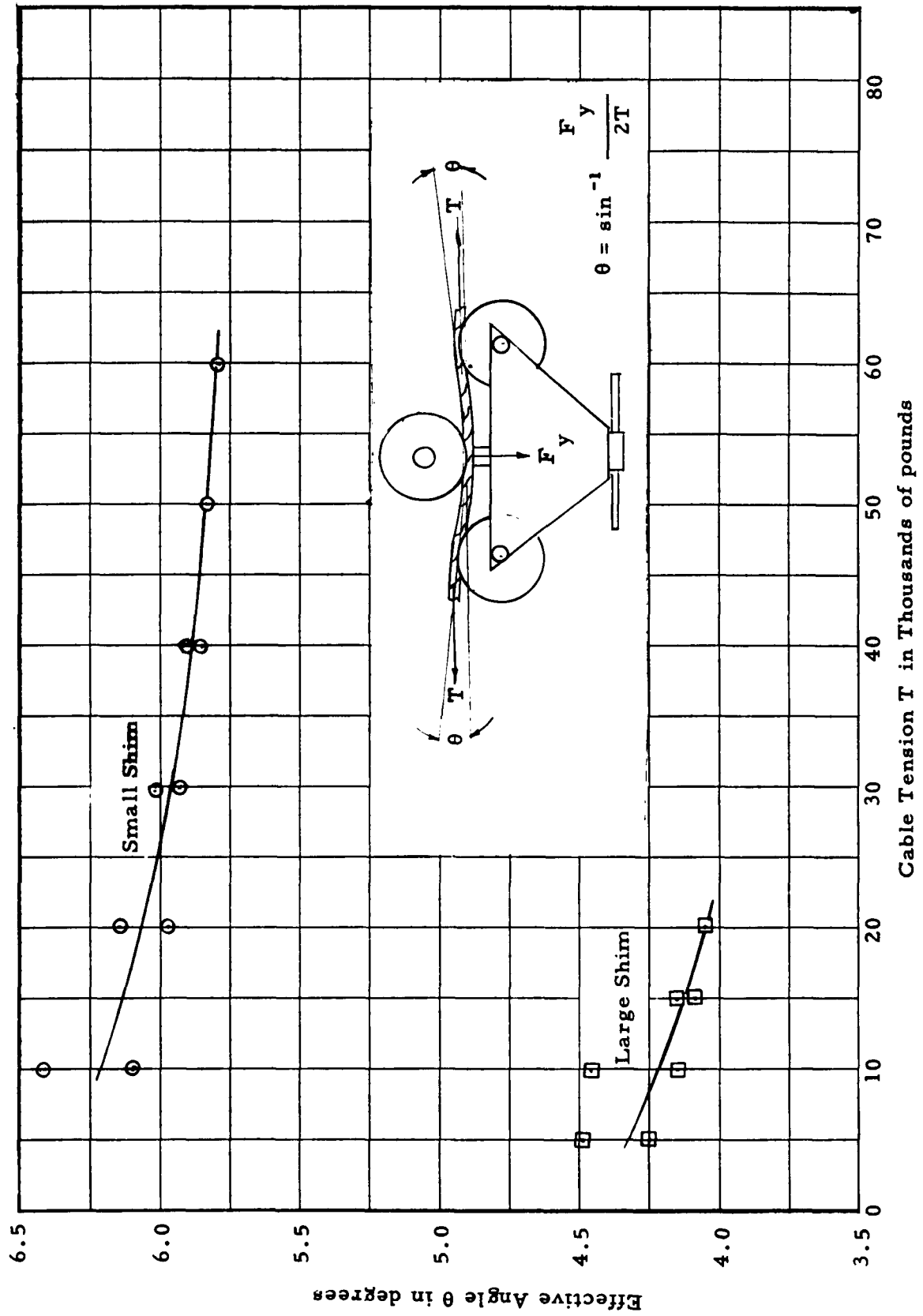


Figure 8 - Effective Cable Angle versus Cable Tension for System A

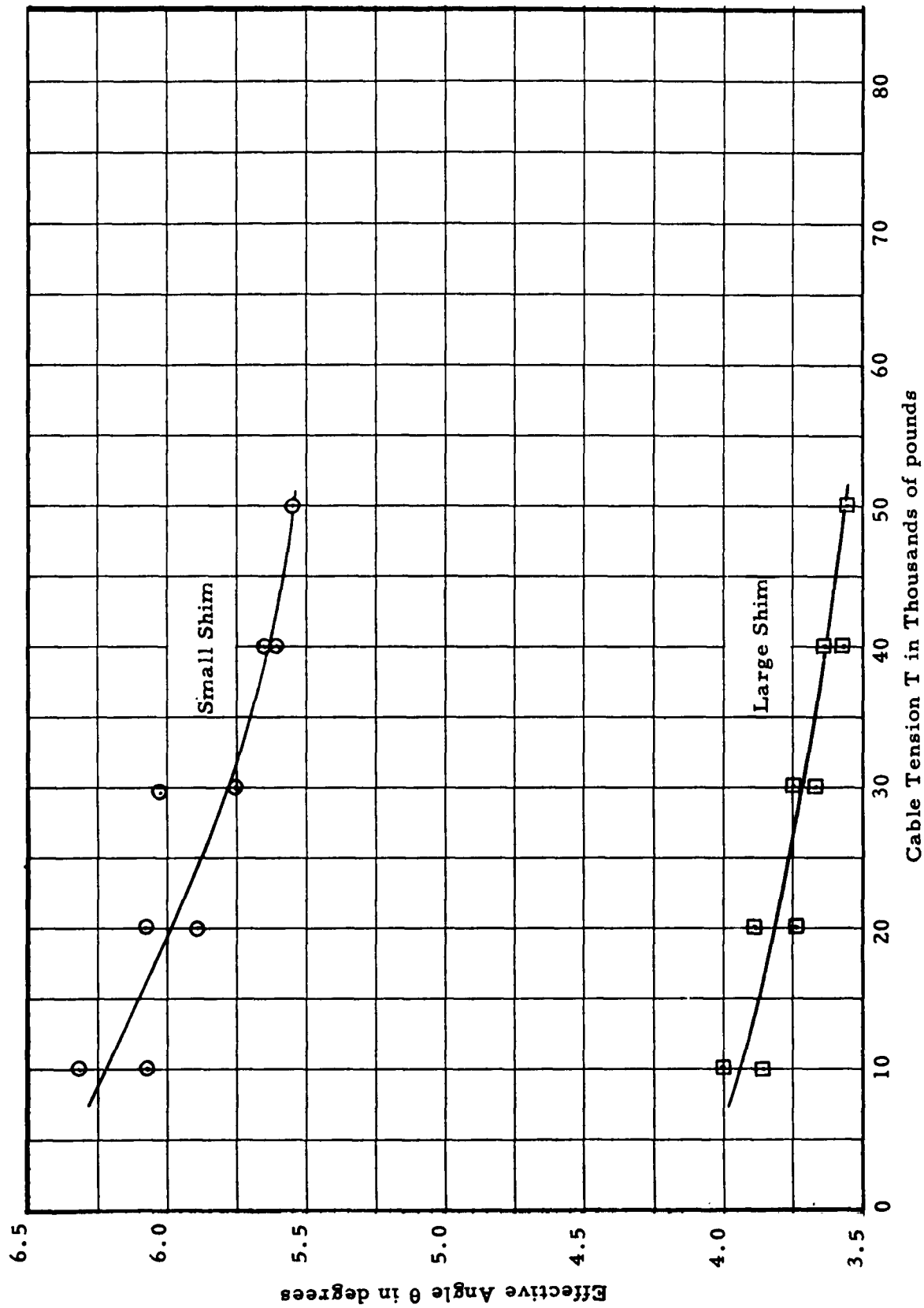


Figure 9 - Effective Cable Angle versus Cable Tension for System B

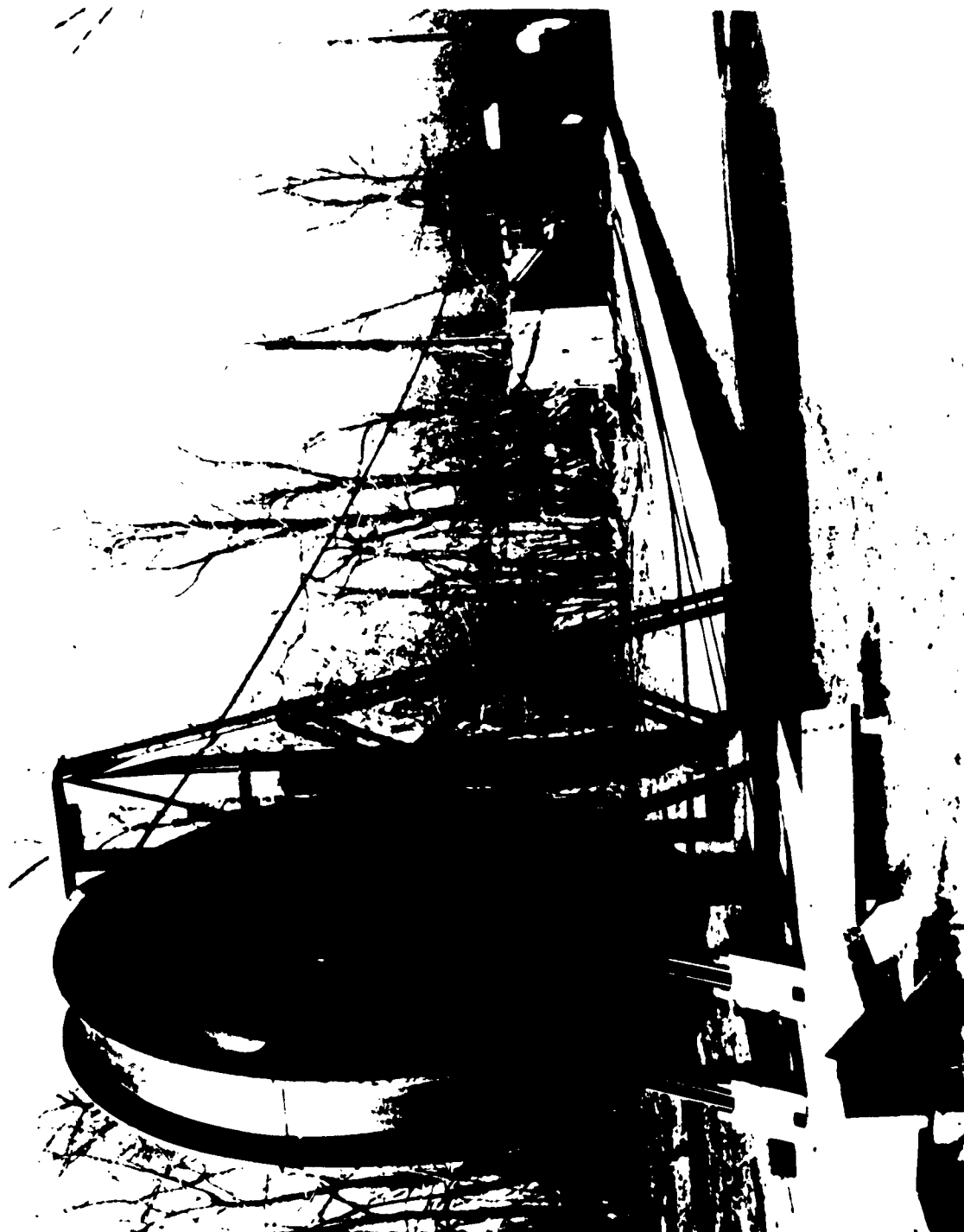


Figure 10 - Test Facility at the Bell Telephone Laboratories

drum is mounted in a frame that can be moved horizontally. A hydraulic ram connected to the frame is capable of exerting a horizontal force of 110,000 pounds.

A schematic of the test arrangement is shown in Figure 11. At the end of the test cable encompassing the drums were wire-rope fittings that fastened to a 100,000-pound capacity TMB load cell. The device was installed near the power drum and was held in place when the test cable was moving by two lengths of 0.25-inch wire rope attached between the frame of the device and rigid points on the test facility. These restraining cables were parallel to the test cable. A 2,000-pound capacity Baldwin load cell was connected in series with one of these cables for measuring the restraining force. Because it was not possible to pass the wire-rope fittings and the TMB load cell over the drums at high tension, the maximum run distance in one direction was limited to 85 feet.

TEST PROCEDURES

The devices were tested separately over a range of cable tensions from 5,000 to 45,000 pounds at cable speeds from 0 to 70 feet per minute. Simultaneous readings of cable tension were taken from each device and the TMB load cell. The restraining force was also recorded at various cable tensions and speeds.

The accuracy of the footage counter was checked by measuring with a steel tape the length of cable that passed through the device. This length was 83.0 feet at a tension of 10,000 pounds and 83.3 feet at 40,000 pounds. Since the counter indicates an addition or subtraction of cable footage (depending on the direction of cable movement) any slippage between the cable and counter sheave was noted on the counter when the cable was returned to its initial position.

The devices and cable were observed for wear and damage during the tests. Motion pictures³ were taken of the device on the moving cable. The cable diameter was measured to determine uniformity at 10-foot intervals within the measured length at different tensions.

PRESENTATION AND DISCUSSION OF RESULTS

Tension readings were practically unaffected by cable speeds from 0 to 70 feet per minute. The maximum discrepancy between simultaneous readings from the device and the 100,000-pound load cell was only 1,800 pounds which was within the accuracy of the measuring system (± 2 percent).

The footage indicator, before modification, indicated only 98.2 percent of the true cable length. This ratio was unchanged for either shim at all tensions. The low footage readings were caused by the longitudinal compression of the cable strands in contact with the counter sheave, a

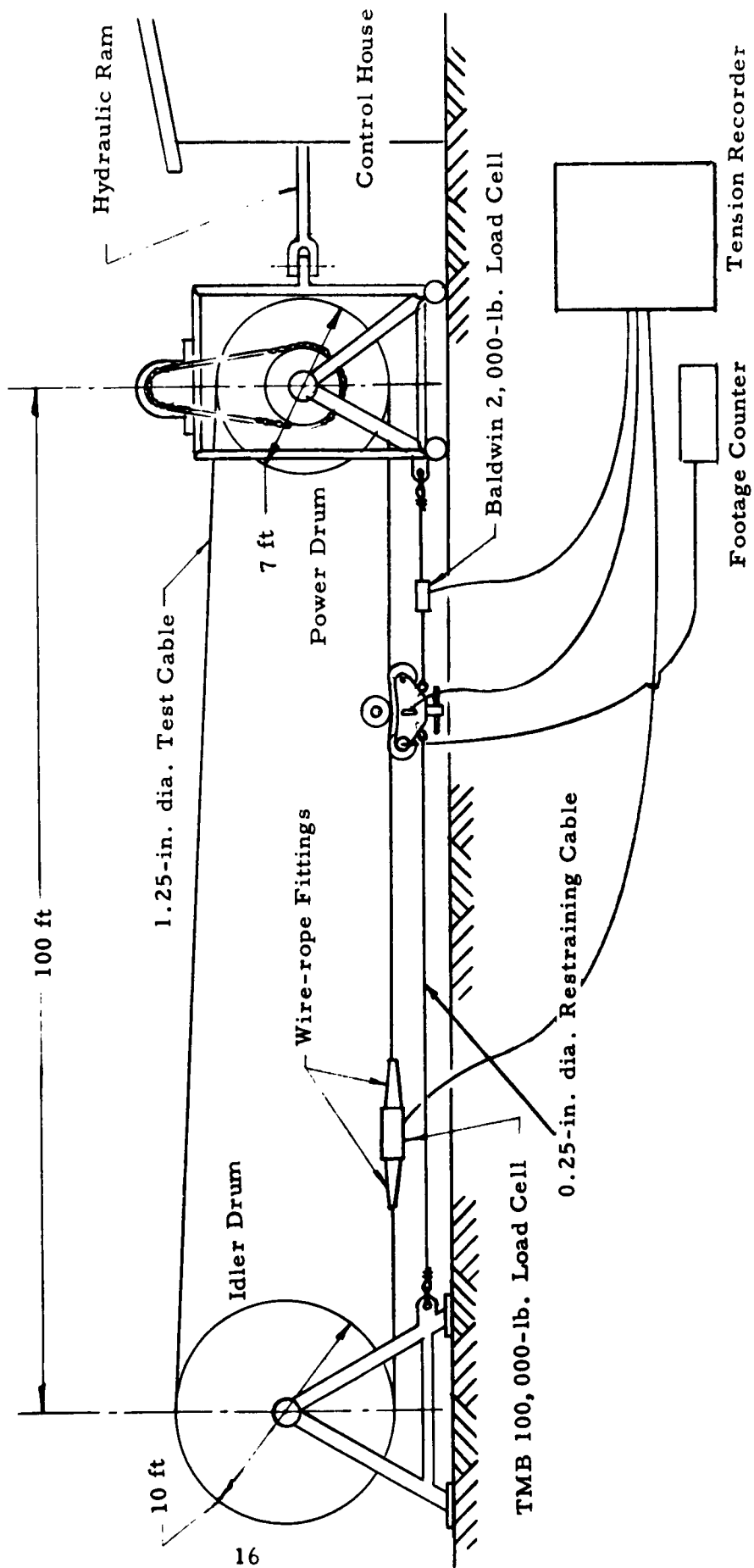


Figure 11 - Schematic of Test Arrangement at the Bell Telephone Laboratories

factor not taken into account in the original design. The situation was remedied by the addition of the set of gears, which were mentioned earlier between the motor and footage counter. There was no slippage between counter sheave and cable for tensions in the range tested.

The cable tension differs from one side of the device to the other because of the restraining force. This differential is shown schematically on the diagram in Figure 12. The device measures a tension intermediate between T_1 and T_2 . However the tension differential between the TMB load cell and the devices was not discernible on the records since the restraining force is only about one percent of the total tension. Figure 12 also shows that the restraining force is directly proportional to cable tension, is independent of cable speed and is small compared with the tension in the cable. Since the restraining force is expected to be greater with the small shim than with the large shim, further tests of this type were considered unnecessary. The magnitude of the restraining force implies that a smaller diameter restraining cable could have been used to secure the device.

Figure 13 shows the variation in cable diameter with station location for tensions of 11,500 and 25,000 pounds. Each plotted point is the average of several measurements around the circumference of the cable. While the magnitude of the diameter variation with station has a negligible effect on the tension readings the change in diameter caused by tension is significant and accounts for the nonlinearity in the tension calibrations and the changes in the effective cable angle. A careful inspection of the test cable on completion of the tests indicated that there was no damage to the cable even though the same length was repeatedly run through the device during the tests.

USE OF SYSTEM IN TOTO II DEEP SEA SHIP MOOR

The installation procedure for the TOTO II deep-sea ship moor is discussed in Reference 4. The success of this installation was due largely to the extensive use of the TMB Cable Tension and Footage Indication System. Figure 14 illustrates the two systems in use during one phase of the operation. They were extremely useful in providing the following information during the installation:

1. Indicated when the anchor bottomed (a sudden drop in tension was observed on the recorder).
2. Indicated water depth (footage reading when anchor bottomed),
3. Provided data to assist coordination between ships when both were paying out cable simultaneously as shown in Figure 14,
4. Provided data to regulate cable tension when transferring cable from storage reels to ship winches.

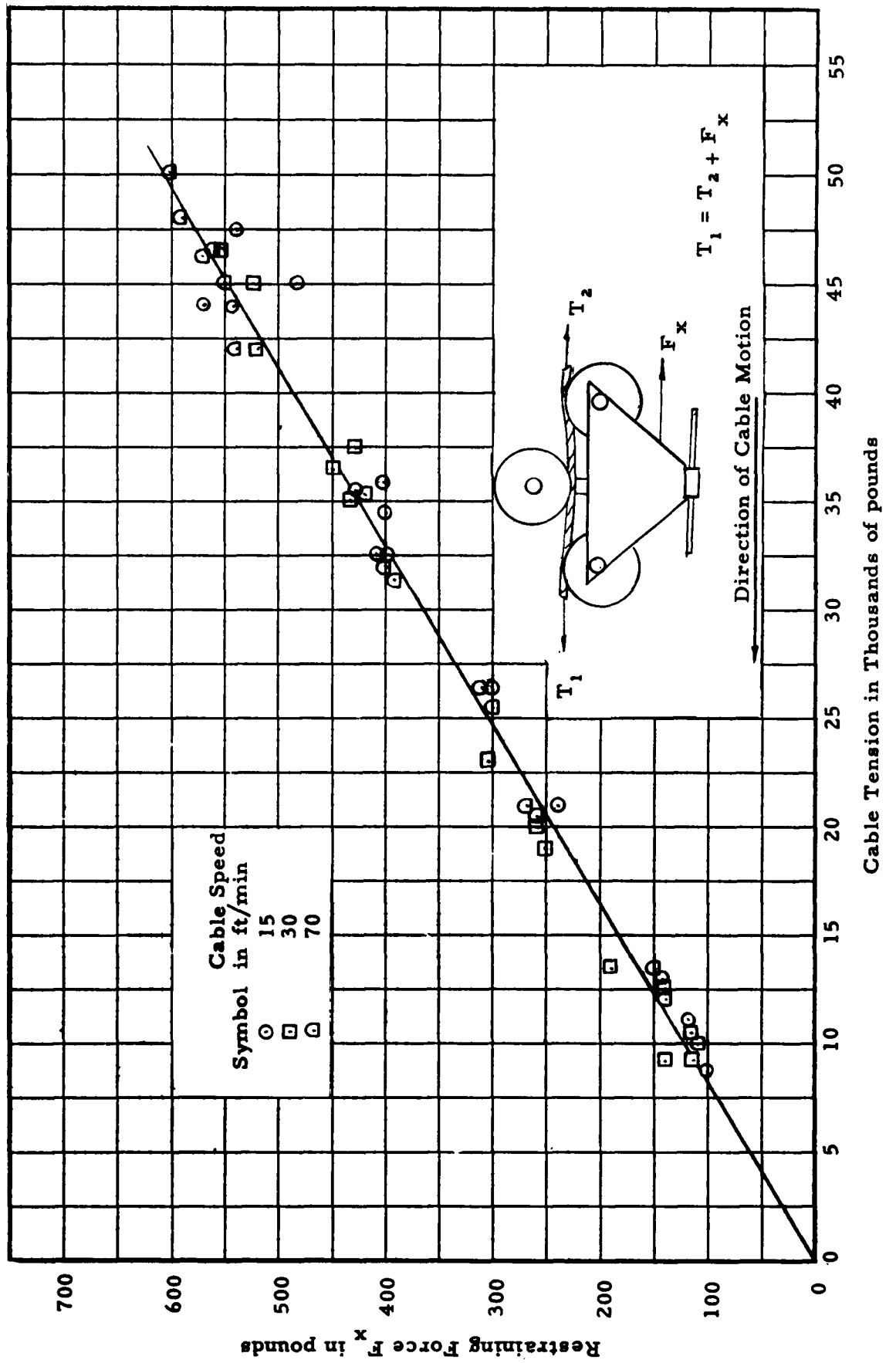


Figure 12 - Device Restraining Force for Small Shim versus Cable Tension at Various Cable Speeds

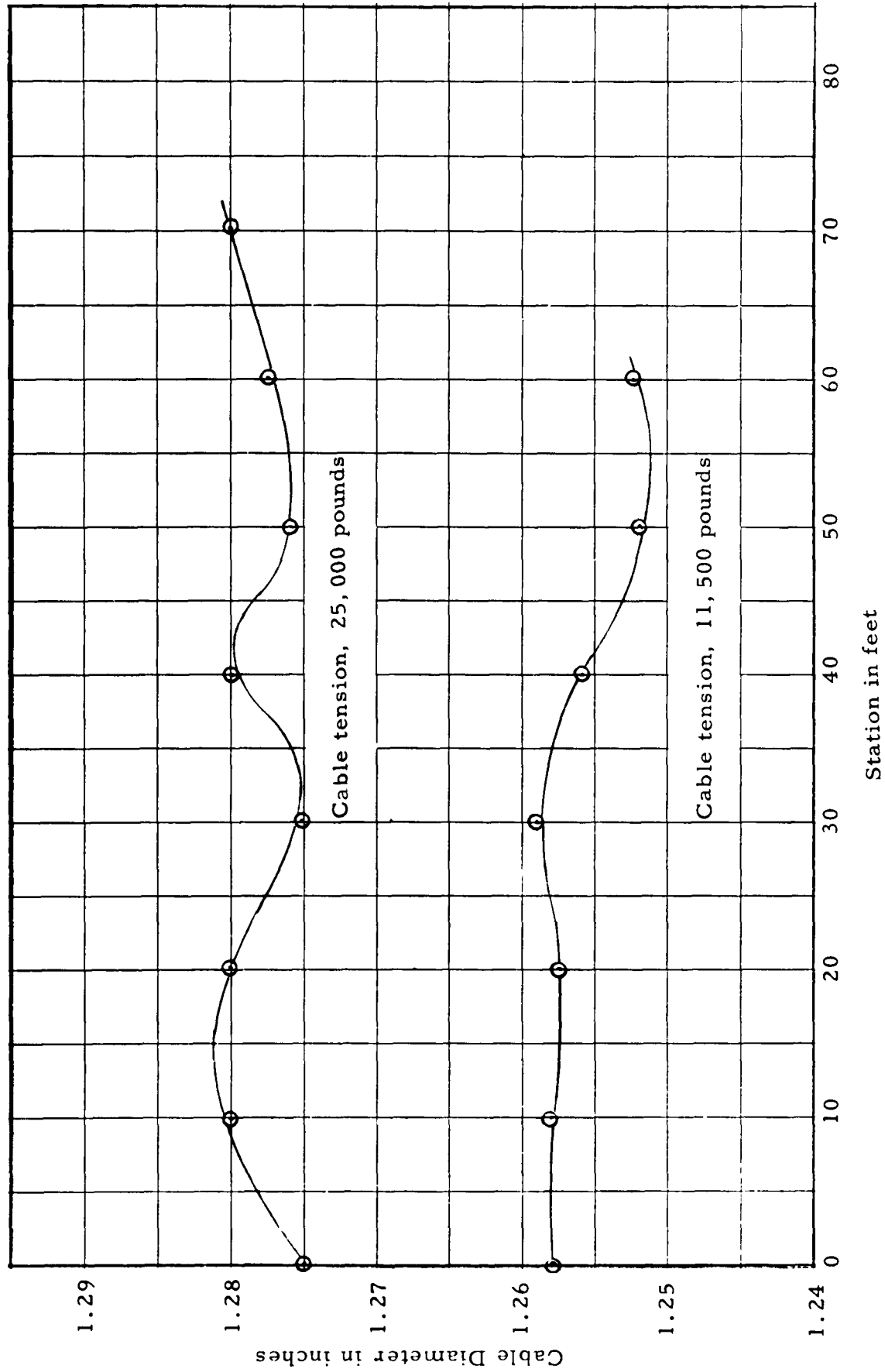


Figure 13 - Variation in Cable Diameter

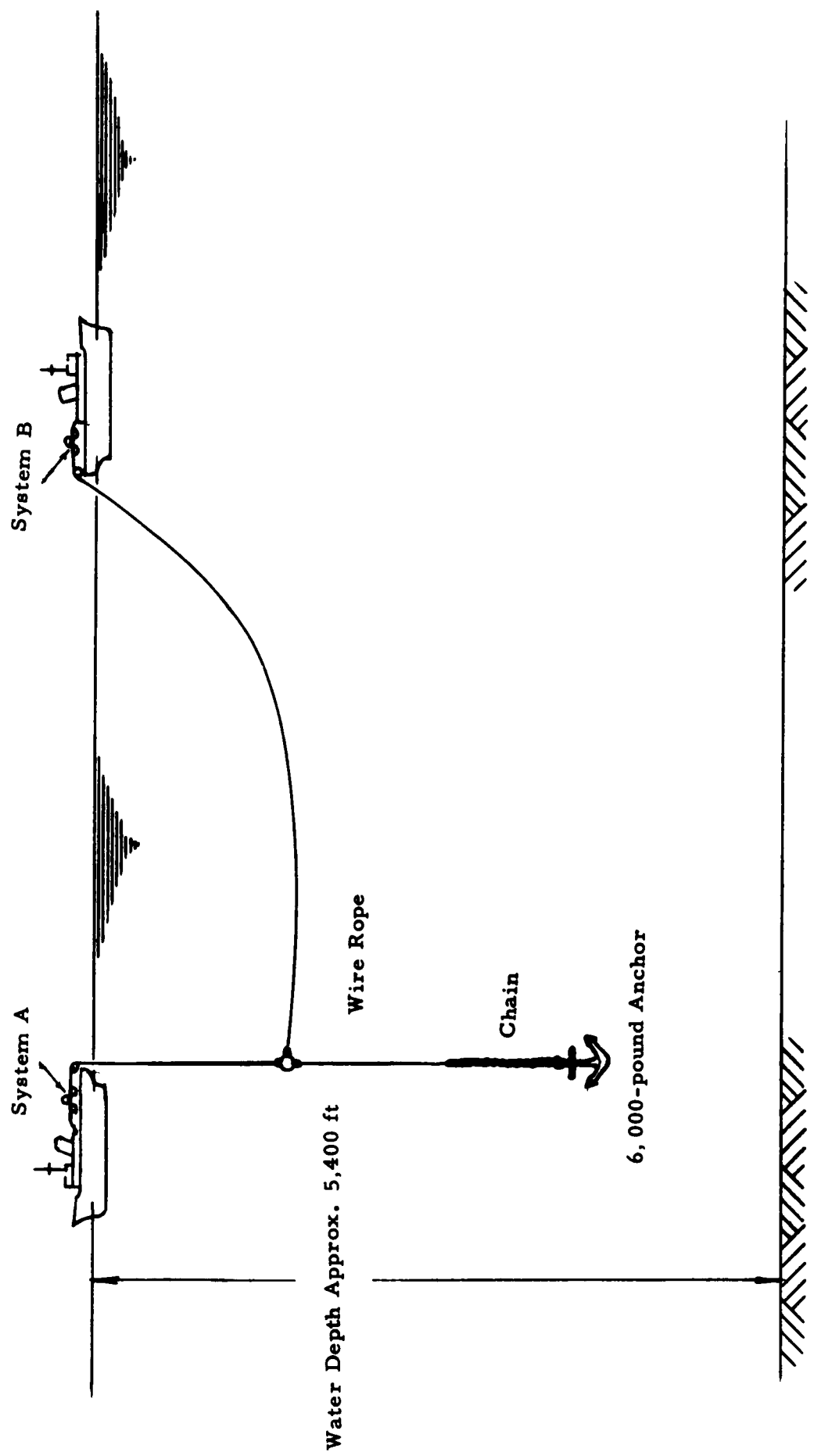


Figure 14 - Schematic of Use of Systems during Installation of the TOTO II Deep-Sea Ship Moor

5. Indicated tension when anchor was being set in bottom.
6. Disclosed whether the anchor was dragging as it was being set in bottom (erratic tension fluctuations when ship was pulling on anchor signified that it was dragging).
7. Determined junction point locations along cable for the connection of various fittings to the cable (footage indication), and
8. Disclosed payout speed when used with a stop watch.

The devices proved to be reliable and rugged even after abusive handling aboard the salvage vessels. During the installation, the devices experienced tensions up to 58,000 pounds and cable payout speeds up to 200 feet per minute. At the completion of the operation, the devices were almost without wear or damage after each had payed out in excess of 40,000 feet of cable. Recalibration of the systems at the Model Basin after the operation showed that there was no discernible change in the original calibrations. A documentary film⁵ is being prepared to show use of the system during the moor installation.

In addition to providing accurate and continuous readings, the system speeded up the installation operation considerably. Three men can install or remove the device from the cable in approximately 2 minutes. Moreover, the improved safety provided by remote readings was evident on several occasions when personnel could have been seriously injured if they had been in the vicinity of the cable.

FUTURE APPLICATIONS

While this system was designed specifically for use with the 1.25-inch diameter cable for the TOTO II moor, it may be possible to use it on cables of smaller diameter. However, the sheave-groove size precludes use on cables of larger diameter. The measurements on cables of smaller diameter may be inaccurate if there is any lateral movement of the cables within the sheave grooves.

If there is a demand for an instrument of this type for a range of cable sizes, the design could be modified with inserts for varying the sheave-groove size and with interchangeable load cells of different capacities. A variable-speed transmission between footage counter and motor would facilitate the calibration of the footage payout system for different size cables.

CONCLUSIONS

Based on calibration tests, proof tests, and actual use during the TOTO II moor installation, the following conclusions are made for the TMB Cable Tension and Footage Indication System:

1. The system furnishes accurate tension and footage measurements. The accuracy of readings is unaffected by cable speeds up to 70 feet per minute and does not appear to be affected by speeds up to 200 feet per minute experienced during the moor installation.
2. The system is portable and the device can be easily installed on a cable by three men. The system can be used anywhere that a 110-volt, 60-cycle per second single-phase, power source is available.
3. The system reduces the time and danger of obtaining measurements compared with previous methods.
4. The device is rugged and reliable, even when subjected to extensive usage.
5. The device does not appear to damage the mooring cable. It is believed that it can be used on armored electrical cables without damage to the cable or conductors.
6. For greater versatility the design can be modified to handle a range of different cable sizes.

ACKNOWLEDGMENTS

The TMB Cable Tension and Footage Indication System was designed by Messrs. L.M. Burgee and H.D. Wynkoop of the Engineering Service Branch. Mr. W.R. Schwarting of the Applied Instrumentation Branch participated in the tests at Bell Telephone Laboratories and in the moor installation.

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