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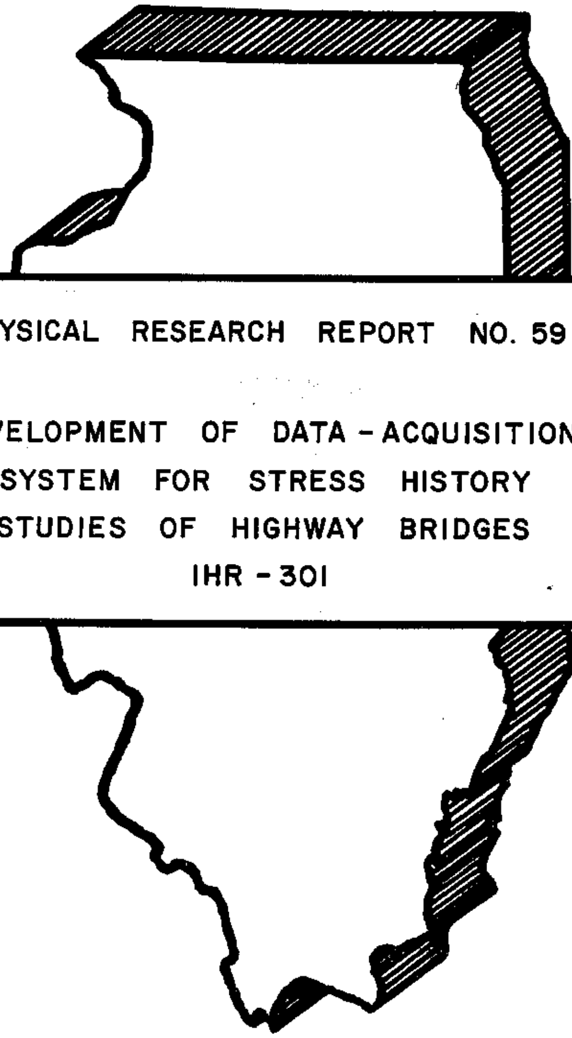

PHYSICAL RESEARCH REPORT NO. 59

DEVELOPMENT OF DATA-ACQUISITION SYSTEM FOR STRESS HISTORY STUDIES OF HIGHWAY BRIDGES

IHR-301

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ILLINOIS DEPARTMENT OF TRANSPORTATION

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Bureau of Materials and Physical Research

DEVELOPMENT OF DATA-ACQUISITION SYSTEM FOR STRESS HISTORY STUDIES OF HIGHWAY BRIDGES

by

Richard K. Taylor and Floyd K. Jacobsen

Interim Report

IHR-301

Life Expectancy of Highway Bridges
Stress History Studies

A Research Project Conducted by
Illinois Department of Transportation
in cooperation with
U.S. Department of Transportation
Federal Highway Administration

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16. Abstract

Of more than 500,000 bridges in service in the nation today, many are known to be inadequate or even unsafe for serving the present and future needs of highway users. Recognizing the need for studying the behavior of existing bridges by compiling large amounts of strain-history data, the Federal Highway Administration encouraged the States to initiate programs for the field testing of highway bridges. In accordance with federal recommendations, the Illinois Department of Transportation has developed an electronic data-acquisition system which can simultaneously record as many as 28 channels of strain data and related information.

The electronic system is housed within a mobile trailer and powered by a portable 10 KW diesel-generator set. The data-acquisition system consists of two 14-channel magnetic tape recorders, and a multi-channel oscillograph for monitoring the data.

This report contains a detailed description of the basic system components and describes the function of the system. The system provides an accurate analog record of strain data and other related information produced by heavily loaded trucks crossing the test structures.

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INTRODUCTION

The collapse of the Silver Creek bridge in 1967 with the tragic loss of 46 lives resulted in a concentrated effort by bridge engineers to determine the condition of existing bridges in the United States. Of the more than 500,000 bridges in the nation, many are known to be inadequate for serving the present and future needs of highway users. The increased volume of truck traffic and the increased axle and gross-weight limits may require the early replacement or upgrading of many structures. A systematic approach for predicting the life expectancy of bridges is needed to budget the necessary funds to insure replacement of structures as they near the end of their useful life.

The present design concepts for fatigue loading of bridges do not consider the effect of actual loads imposed on the structure throughout its life. Strain-history information relating the strains induced in highway bridges by heavy trucks to the actual weight of the trucks is very limited. Recognizing the need for compiling large amounts of strain-history data, the Federal Highway Administration developed a pilot system for collecting such data on bridges located throughout the country. It was apparent, however, that the collection of sufficient data would require that the states develop their own systems for compiling and analyzing strain data.

On March 1, 1968, the Federal Highway Administration distributed a circular memorandum encouraging the states to initiate programs for the field testing of highway bridges. The primary problems to be considered included the development of an electronic data-acquisition system and the development of suitable techniques for analyzing the data.

Because of prior research experience in the field of highway bridges, the University of Illinois is in a unique position to carry out a program of collecting and analyzing extensive amounts of strain data compiled during field tests of bridges. An earlier study originally proposed in 1948, Project IHR-9, "Impact on Highway Bridges," provided information on the theoretical behavior of bridges which could serve as a guide for future analysis of strain data collected during field studies. The original proposal for IHR-9 included provisions for a series of field tests to be correlated with the theoretical results. However, it soon became apparent that sufficient knowledge of the theoretical behavior of bridges was not available to guide the development of a field-testing program. Consequently, the results of IHR-9 were based on tests conducted on prototypes and small-scale laboratory models, and not upon the results of field tests on structures in service.

In 1966 the study, IHR-85, "Dynamic Stresses in Highway Bridges," was initiated to provide data from the field testing of bridges to validate the analytical results of IHR-9. Because of its limited scope, IHR-85 has been primarily a pilot study which led to the development of a field-test capability and techniques including computer programs for data reduction and analysis.

The study has been conducted as a joint effort of the University of Illinois, the Federal Highway Administration, and the Illinois Department of Transportation. During the early stages of the project, the Federal Highway Administration provided most of the instrumentation and equipment needed to conduct the tests. The University supplied the required supplementary equipment and was primarily responsible for the collection and analysis of the data. The Illinois Department of Transportation arranged the tests and assisted with the instrumentation of the structures and the collection of data.

As the study progressed, the equipment and personnel furnished by the Federal Highway Administration were no longer available, and the required field test equipment was supplied by the University. The Illinois Department of Transportation continued to schedule and organize the tests, instrument the structures, and assist in collecting the data.

The present study, IHR-301, "Life Expectancy of Highway Bridges," was proposed in 1970 as the next step toward analyzing the effect of dynamic loads on bridges. By combining the theoretical knowledge acquired from IHR-9 with the field testing experience gained from IHR-85, the present study was developed to yield considerable insight into the dynamic behavior of bridges in service, and to provide a basis for predicting the life expectancy of bridges.

Although the prior study was conducted with equipment furnished by the Federal Highway Administration and the University of Illinois, the equipment was only supplied on a temporary basis until the Illinois Department of Transportation could develop a comparable data-collection capability. This report covers Phase I of the present study (IHR-301), and includes the development by the Illinois Department of Transportation of an electronic data-acquisition system and a field-test capability for obtaining stress history data.

RESEARCH OBJECTIVES

The primary objective of this study is to develop and verify reliable techniques for predicting the life expectancy of existing and future highway bridges. A meaningful statistical relationship between loads imposed on bridges and the life expectancy of bridges depends upon the acquisition of a voluminous amount of strain data to provide a sufficient sample for accurate analysis. Therefore, the first step toward achieving the objective of this study is to accumulate and analyze a statistically meaningful quantity of data on the live-load stresses induced in bridge members under high-volume mixed traffic. Ideally, the test structures will be located near truck weigh scales to allow a correlation of the static truck weight and the dynamic stresses induced in the bridge.

A secondary objective of this study is to test selected "problem" structures for which a detailed analysis would be beneficial. It is envisioned that a substantial contribution to public safety can be realized by developing a system for acquiring data for making a thorough investigation of such structures.

DESCRIPTION OF DATA-ACQUISITION SYSTEM

The development of a field-test capability for obtaining strain-history data was the first major phase of this project. The data-acquisition system was designed as a mobile unit consisting basically of two high-quality 14-channel tape recorders and associated signal-conditioning components for monitoring 28 data channels. The test data are recorded on magnetic tape in analog form which is later converted to digital form at the University of Illinois for processing by the computer analysis system employed by the University.

The electronic system is housed in an 8- by 20-ft mobile trailer which is easily transported to a test site (Figure 1). The temperature and humidity within the trailer are controlled by two 10,000 BTU air conditioners and a 30,000 BTU propane heater. Power for the mobile unit is supplied by a 10 KW diesel-generator set mounted on a two-wheeled trailer.

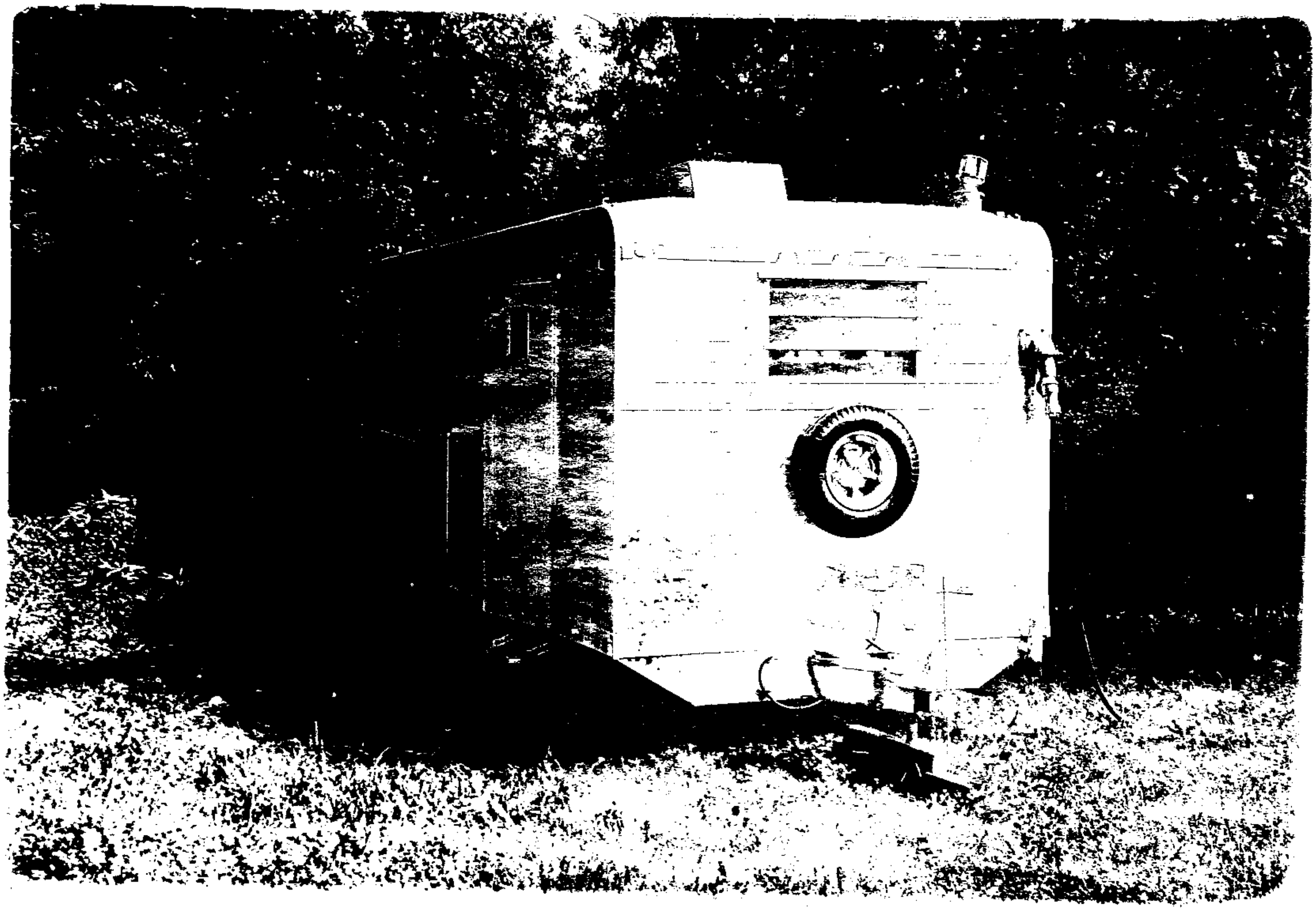

Figure 1. Mobile instrumentation van.

The tape recorders and electronic components are assembled into a two-rack console which is permanently mounted in the mobile trailer (Figure 2). The console also includes a multi-channel direct recording oscillograph for monitoring various channels as the data are recorded on the magnetic tape. A schematic of the data system is shown in Figure 3.

The following section provides a general outline of the function of the data system.

General Function of System

The primary function of the data acquisition system is to obtain strain information at strategic locations on bridge members as heavily loaded trucks cross the test structures. In addition to strain gage information, data from deflection gages located on bridge girders and from accelerometers placed at critical locations on the structures are also recorded.

A typical cycle for collecting strain data begins as a truck reaches a location about 500 feet from the approach end of the bridge. At this point a microphone senses the noise from the truck and transmits a signal to an amplifier in the van housing the electronic equipment. The signal engages a relay which activates a timer and starts the recorder. Approximately one second after the recorder is started, a calibration pulse representing a known strain is automatically recorded on the tape. The duration of the calibration pulse is about three seconds. After the recorder starts, a brief verbal description of the truck is also recorded as the truck approaches the bridge.

As the truck enters the bridge, each axle interrupts a beam of light passing from a light source on one side of the bridge into a photo cell on the other side of the bridge. As each axle cuts the light ray, a pulse is transmitted to the instrumentation van and recorded on one channel of the magnetic tape. An identical light source and

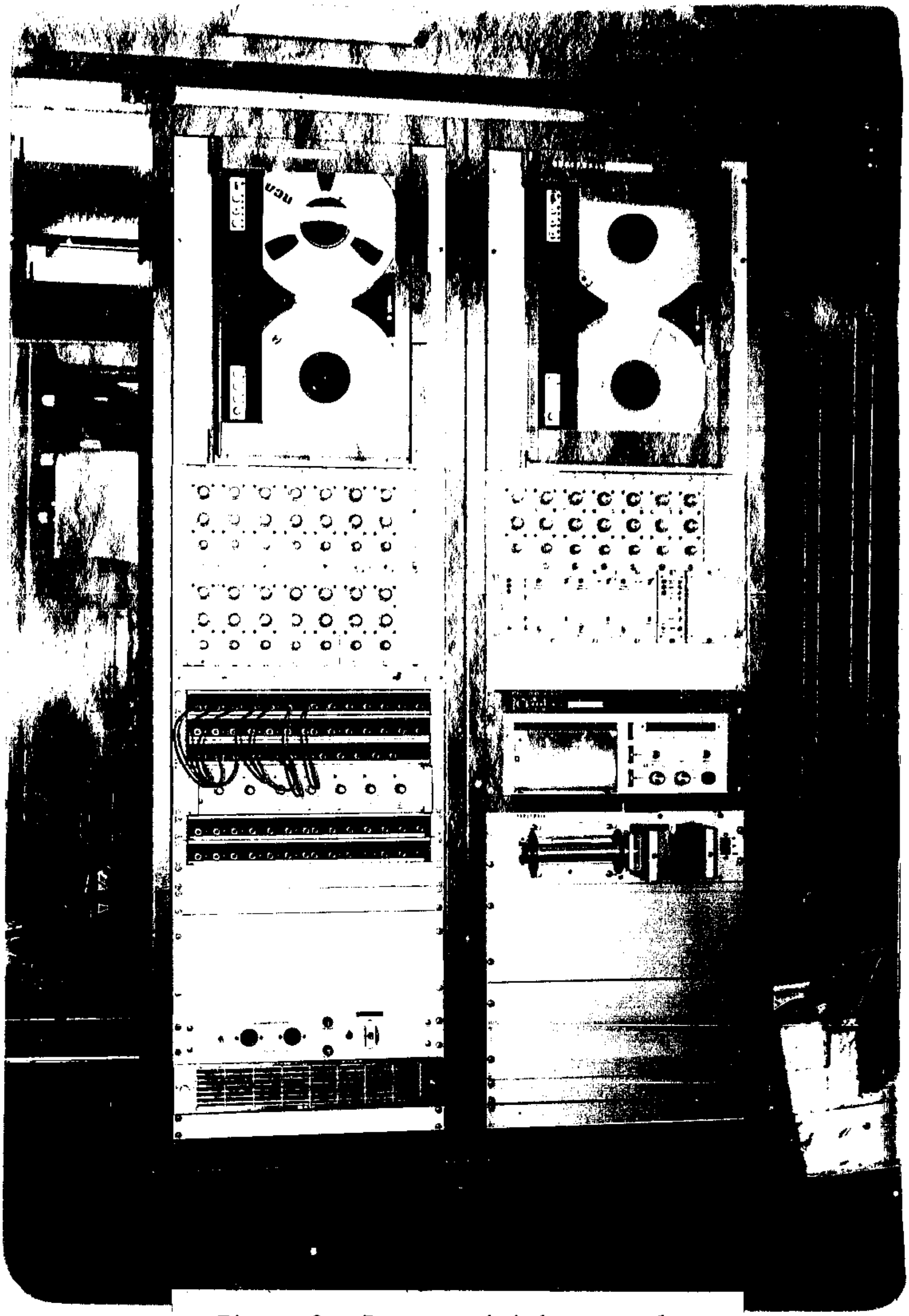

Figure 2. Data-acquisition console.

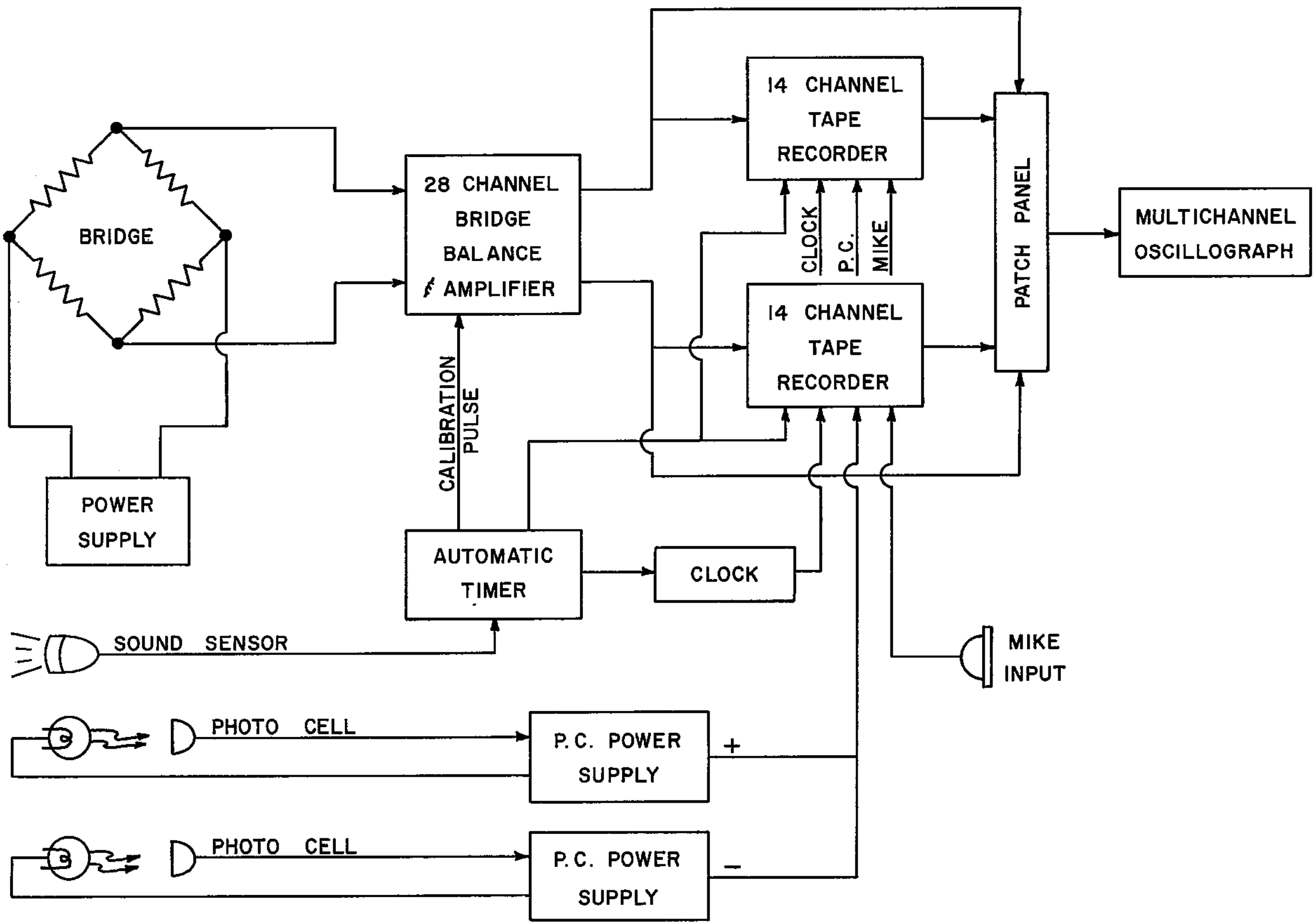

Figure 3. Schematic of data-acquisition system.

photo cell located at the exit of the bridge also records each axle as it leaves the bridge. From the two photo cells located a known distance apart, the speed of the truck as it crosses the bridge may be determined.

Strain data and related information are recorded during the time that the truck is on the structure. The timer is automatically set to turn the recorder off at a predetermined time after the truck has left the bridge.

Should a second truck or several trucks approach the bridge before the timing cycle from the first truck is completed, the recording is extended by a second relay which resets the timing cycles.

The following section provides a detailed description of the mobile unit and the recording system components. Specifications for the system and for the electronic components are appended to this report.

Instrumentation Van

The initial expenditure made for the project was for the purchase of an 8- by 20-ft instrumentation trailer needed to house the electronic equipment and to transport it from the laboratory to the test structures. The van was furnished with a 30,000 BTU L/P gas furnace and two 10,000 BTU air conditioners used for controlling the environment of the electronic equipment.

The trailer was delivered in March 1971 and stored in the garage of the Physical Research Laboratory until the first phase of electronic equipment was delivered. In August 1971, the first stage of instrumentation was received from Honeywell, Inc., of Denver, Colorado. A rack delivered with the first stage of equipment was installed in the trailer, with shock mounts to minimize any disturbance of the equipment during transit. The equipment was then mounted in the rack and checked out by representatives of Honeywell prior to conducting a trial field test during November 1971.

Magnetic Tape Recorders

The Honeywell Model 5600 tape system includes two vertical rack-mounted 14-channel instrumentation grade recorders capable of recording at seven selectable servo-controlled tape speeds of 15/16, 1 7/8, 3 3/4, 7 1/2, 15, 30, or 60 in. per second, and capable of reproducing at two of the seven speeds (Figure 4). All data collected during this research study will be recorded at a tape speed of 3 3/4 in. per second, which is the optimum speed for processing the data at the University of Illinois.

Optional methods of data handling by this recorder include direct (analog), FM, and serial digital. In order to attain a more accurate reproduction of data, the FM method is used for this project. The bias version of the FM system uses a single 1.25 MHz bias oscillator to supply the bias signal for all data channels. The oscillator has two 180 degree out-of-phase outputs that are fed to alternate data channels to reduce interference between data tracks.

One record amplifier is required for each FM data channel to amplify the input data signal which is used to frequency modulate a VCO (voltage controlled oscillator) developed carrier. The frequency modulated signal is amplified and mixed with the bias signal before output to the recording head. The standard magnetic head assemblies are 14-track, 1-in. interleaved head stacks compatible with IRIG (Inter-Range Instrumentation Group) standards.

The tape transport accommodates 10 1/2-in. reels of 1/4-in., 1/2-in., or 1-in. wide tape on 3-in. hubs. The 1-in. wide tape is used for recording the data for this study. Flutter, skew, and time-displacement error are minimized by the servo-controlled tricapstan drive and independent reel servos.

The capstan drive servo provides primary control of tape motion for the system. The servo controls tape speed acceleration and deceleration during mode changes, and maintains tape motion at the exact speed selected. The capstan servo may be controlled by the output from the capstan tonewheel, an external reference oscillator, or a prerecorded control track on the tape.

Figure 4. Magnetic tape recorder.

The dual reel servo controls the operation of the supply and takeup reel motors. The reel servo follows the movement of the capstan servo as controlled by the reel servo tension arms. Each tension arm determines the tension required for the tape between the secondary capstan roller and that reel, and varies a potentiometer controlling the input signal to one of the two power amplifier sections of the dual reel servo amplifier card. The power output from each amplifier section is used to drive a reel motor to maintain tension. When the reel servo tension arms are fully released by a break in the tape or the end-of-tape, they generate a tape-break signal that terminates the tape motion.

Gage-Control and Amplifier Unit

In most cases the strain gage configurations used in this project will consist of full Wheatstone bridges with either single or double active arms. The Accudata 118 Gage-Control and Amplifier Unit is used to supply the excitation voltage to the various gage arrangements (Figure 5). The unit is a signal-conditioning instrument that contains bridge balance and calibration circuitry to control gage excitation and balance. The instrument also serves as an amplifier which was specially modified at the factory to provide an upper gain limit of 2800. The signal from the strain gages is amplified by the Accudata 118 before being recorded on the magnetic tape.

The first step in adjusting the strain bridge amplifier circuit is to check the excitation voltage across the strain bridge. An excitation voltage of 5 volts DC is applied across each strain gage bridge. Next, one side of the strain gage bridge is disconnected from the amplifier, and the output of the amplifier is balanced to zero. The strain gage bridge is then reconnected to the amplifier and the total circuit is adjusted to zero. The preparation for testing is completed by placing a calibration resistor in parallel with opposite gage arms of

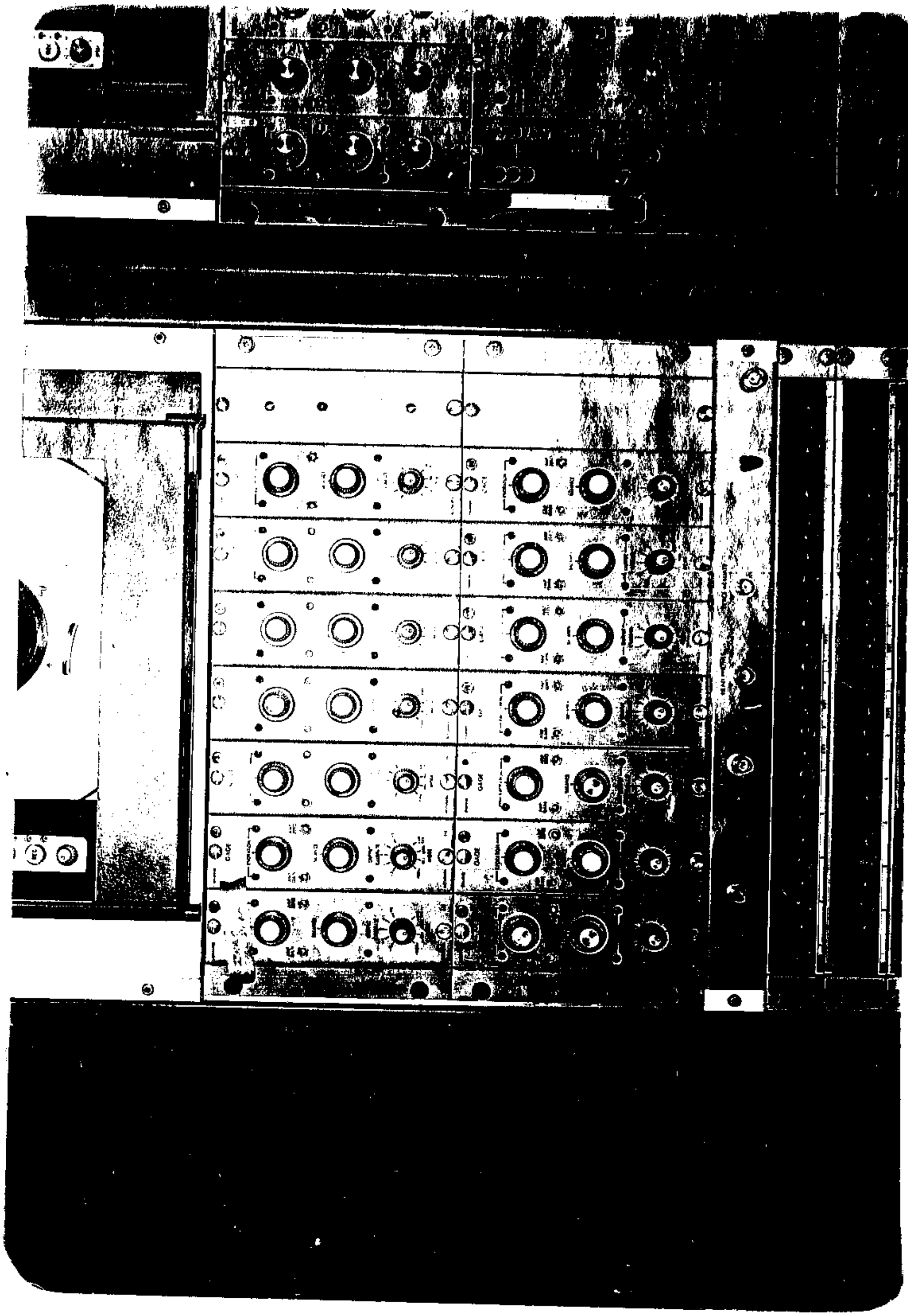

Figure 5. Gage-control and amplifier unit.

the balanced strain gage bridge. This produces an imbalance in the bridge, simulating a strain on the gage. The value of the calibration is calculated to represent a known strain. The magnitude of deflection of the recorded pulse then becomes a calibration unit to evaluate test results.

Reproduction System

During the testing, the signal may be monitored by a multi-channel direct-recording oscillograph (Figure 6). The signal from the amplifier can be monitored before being recorded on the tape by connecting the input of the tape recorder to the input of the oscillograph. The signal may also be monitored after being recorded on the tape by connecting the output of the tape recorder to the input of the oscillograph.

When monitoring the output of the tape recorder, the FM reproduction system uses quad analog preamplifiers. Each preamplifier has four identical and separate preamplifiers and can handle four separate data channels. The preamplifier amplifies the head output to a level usable by the reproduce amplifier.

One FM reproduce amplifier is required for each FM data channel. Each reproduce amplifier has positions for two center carrier frequency filter modules so that the amplifier may function at either of two selected tape speeds. The signal from the preamplifier is demodulated and amplified to restore the data signal to its original form.

The signal then enters the Accudata 117 multi-channel DC amplifier with seven direct coupled amplifiers used to drive the galvanometers within the oscillograph. The oscillograph uses a high-pressure mercury vapor lamp that emits high-intensity ultra-violet light, which is reflected from miniature mirror galvanometers through a precision optical system onto the recording paper. The recording paper is sensitive to ultra-violet light and produces instantly readable traces on exposure to

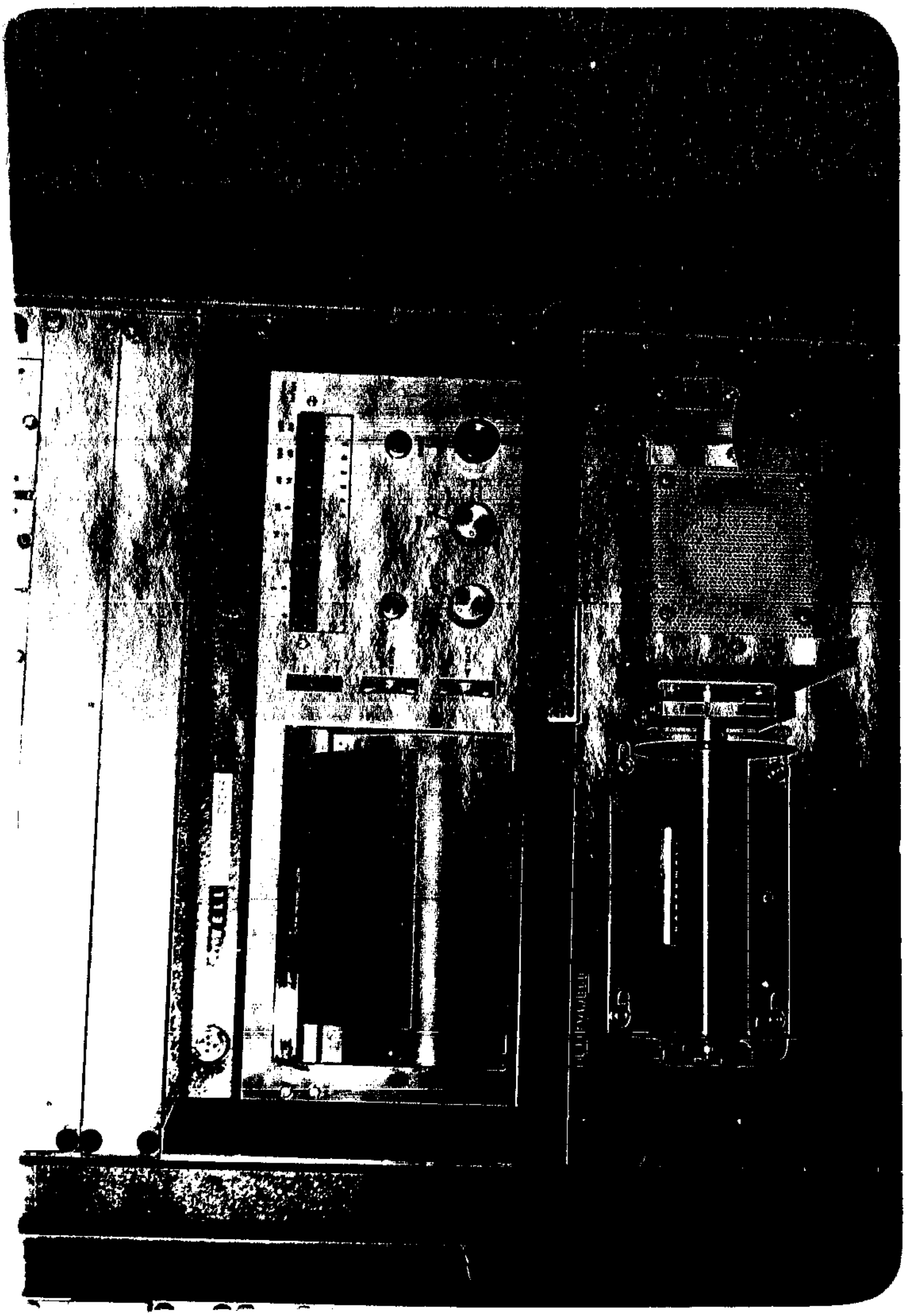

Figure 6. Multi-channel direct-recording oscillograph.

fluorescent light or another source of low-intensity ultra-violet light. Traces remain legible for long periods under normal room lighting and last indefinitely if stored in a file.

Automatic Timer-Programmer

The start and duration of each cycle is controlled by an automatic timer-programmer (Figure 7) which regulates four functions as follows:

(1) Start-up of the recorder.

(2) Delay in the beginning of the calibration pulse.

(3) Start and duration of the calibration pulse.

(4) Delay and beginning of the recording of clock time.

The programmer is activated when a microphone on the roadside picks up the noise of an approaching truck. A signal is then transmitted to a solid state integrated circuit which operates relays to control the timing of the various functions. First, the recorder is started and a delay circuit is activated which delays the start of the calibration pulse for a predetermined length of time, usually equal to one second. The calibration pulse, lasting for about three seconds, is then recorded on the tape. The digital clock is initially shorted out to provide a reference on tape to indicate the beginning of each cycle. When the calibration pulse is half completed, time from the digital clock is recorded for the remainder of the cycle.

The duration of each cycle can be adjusted to last 15 ± 10 sec. If a second truck approaches before the cycle from the first truck is completed, the input to the integrated circuit generates a renewal of the total cycle time; however, the output from the integrated circuit does not change, which eliminates a renewal of the calibration pulse. With this feature, the strain from a number of trucks in

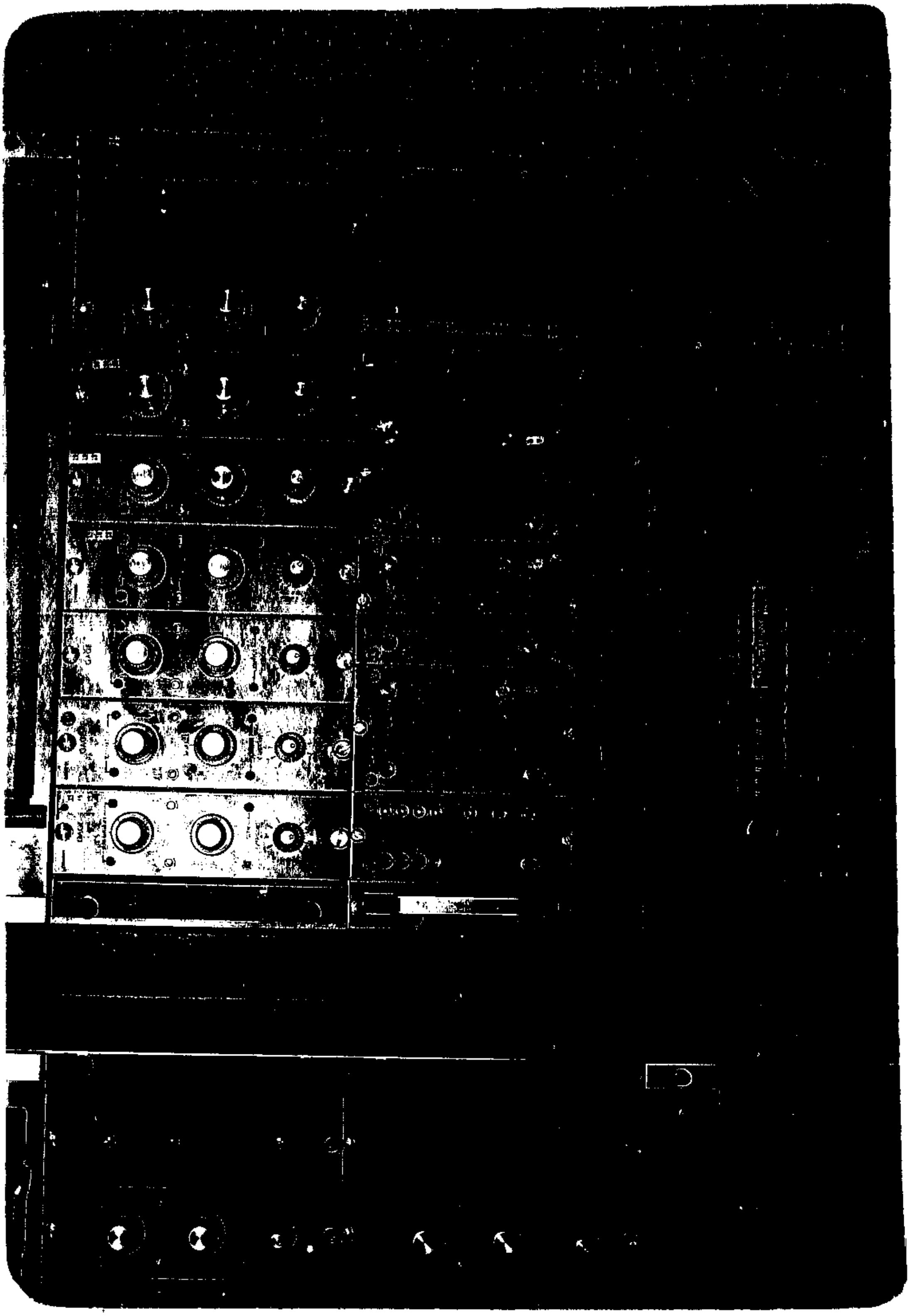

Figure 7. Automatic timer-programmer.

succession can be recorded continuously without interruption by a calibration pulse.

If a number of trucks pass the microphone without triggering the system, the sensitivity of the microphone in picking up the noise level of approaching traffic can be adjusted from a rack-mounted module within the instrumentation van. Indicator lamps on the front panel of the module indicate when the various functions are performed. The duration of each function can also be adjusted from the module.

Photo Cells

At the entrance and exit of each test structure, photo cells are placed to detect each axle as it enters and leaves the bridge (Figure 8). By spacing the photo cells a known distance apart, the speed of the trucks as they cross the bridge may be determined.

At each end of the structure a light source is placed on one side of the bridge which beams a light ray into a photo-cell pickup located on the other side of the bridge. The light source consists of a sealed beam aircraft landing light mounted on a steel plate supported by three adjustable legs. The pickup consists of a photo transistor with an optical lens to receive the light beam from the source. The unit is also mounted on three adjustable legs and contains a target with a view lens to facilitate the alignment of the units in the field. The pickup is sensitive to light from a broad spectrum which reduces the effects of changing ambient light on the operation of the system.

The photo-cell system operates from an independent power supply located in a rack-mounted module within the instrumentation van. The module also includes an indicator light which flashes when the photo cells are functioning, a test switch to interrupt the light source and simulate the passing of an axle to check the operation of the system, and a polarity selector switch used to reverse the polarity

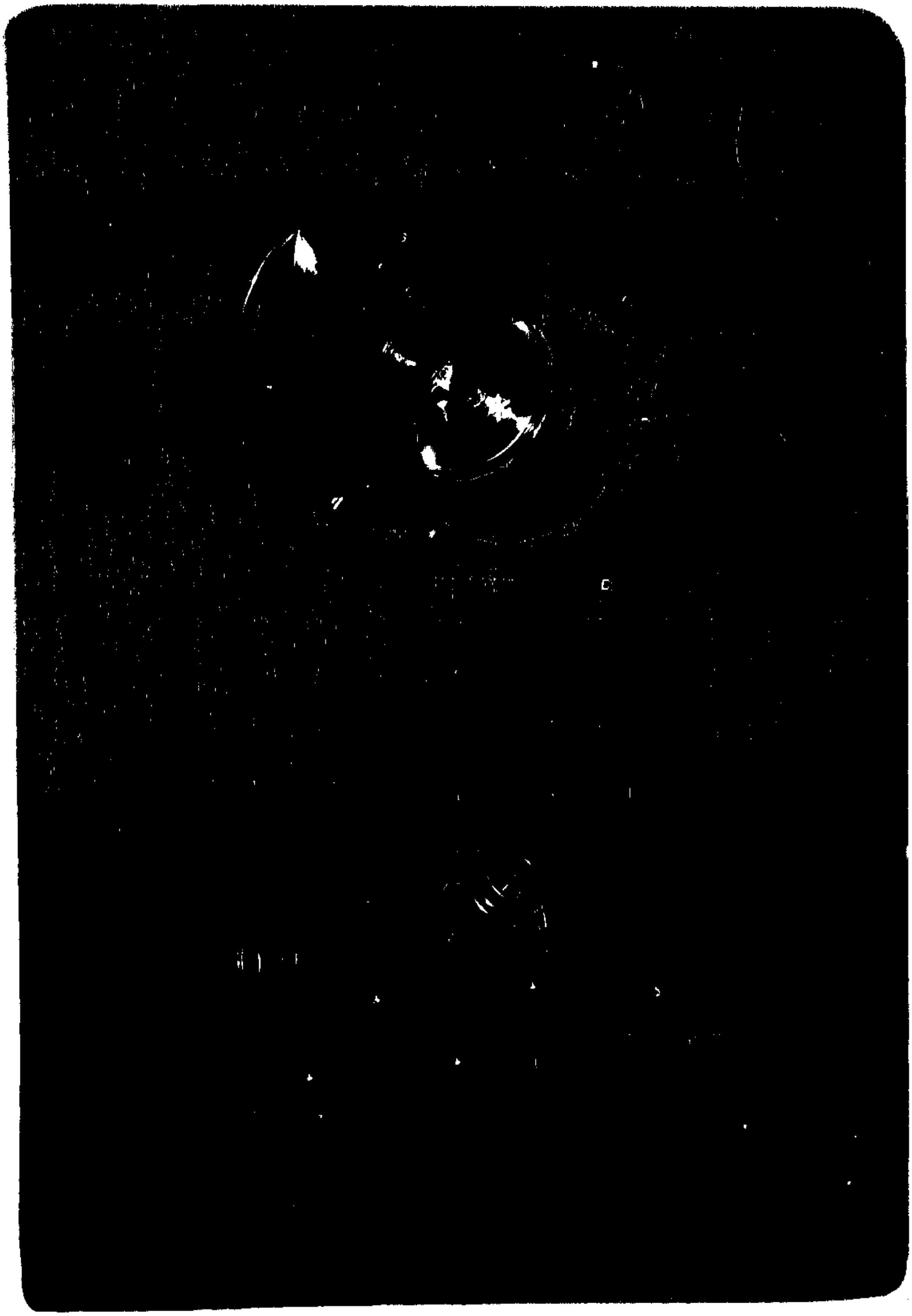

Figure 8. Photo cell and light source.

of the entrance and exit cells to provide a means of distinguishing between the output of the two units.

Portable Power Supply

A trailer-mounted Onan 10 KW diesel-generator set was purchased to provide a portable power supply for operating the electronic equipment during the field tests. The 4-cycle diesel engine is capable of developing no less than 24.0 horsepower at its operating speed of 1800 rpm and provides continuous service on 120/240 volts single-phase AC.

The generator is rated at 12 KW for standby service and 10 KW for continuous service. The overload capacity is 150% of rated continuous amperes for 10 minutes or 125% of rated continuous amperes for 2 hours.

The voltage regulation provides a $\pm$ 3% voltage dip and overshoot less than 12% with recovery to stable operation in less than 2 seconds on application or removal of rated load in one step.

The diesel-generator set, fuel tank, and batteries with racks are mounted on a single-axle utility trailer.

DESCRIPTION OF INSTRUMENTATION

The instrumentation installed to collect information relative to the behavior of the test structures includes strain gages, deflection gages, and accelerometers. Most of the strain gages are bonded to the steel superstructure at strategic locations such as the center of a span or near cover plate cut-off points. On certain structures, reinforcement bars within the reinforced concrete decks are exposed and instrumented with strain gages. The deflection gages and accelerometers usually are located at midspan where the deflections and vibrations are of largest magnitude.

A description of the type of equipment used to instrument the structures is as follows:

Strain Gages

The type of strain gages selected to instrument bridge superstructures are the BLH A-1-S6 paper-backed wire gages which are temperature-compensated for application to steel members. The gages have gage resistances of 120.0 ± .2 ohms and gage factors of 2.03 ± 1.0 percent. These gages have proven to be reliable for these relatively short-term field applications lasting up to approximately six months. The durability of the gages is dependent upon proper installation techniques which are described in the section covering instrumentation procedures.

Deflection Gages

On certain structures, deflection gages similar to those used by the Federal Highway Administration are mounted at the midspan of the bridge beams to measure the deflections of the beams as heavy trucks cross the structure (Figure 9). The deflection gages consist of tapered aluminum plates to which are mounted strain gages in a full four-arm Wheatstone bridge configuration. The type of strain gages mounted on the deflection gages are the BLH A-1-S13 paper-backed wire gages which are temperature-compensated for aluminum. Each deflection gage is calibrated to produce a known strain for each 0.1 in. increment of deflection.

The deflection gages are securely fastened to the underneath sides of the lower flanges of the beams with C-clamps (Figure 10). The pointed end of the gage, which behaves as the free end of a cantilever beam, is deflected downward and held in the deflected position by a wire stretched from the end of the gage to an anchor located on the ground. As the beam deflects, the deflection of the gage is reduced,

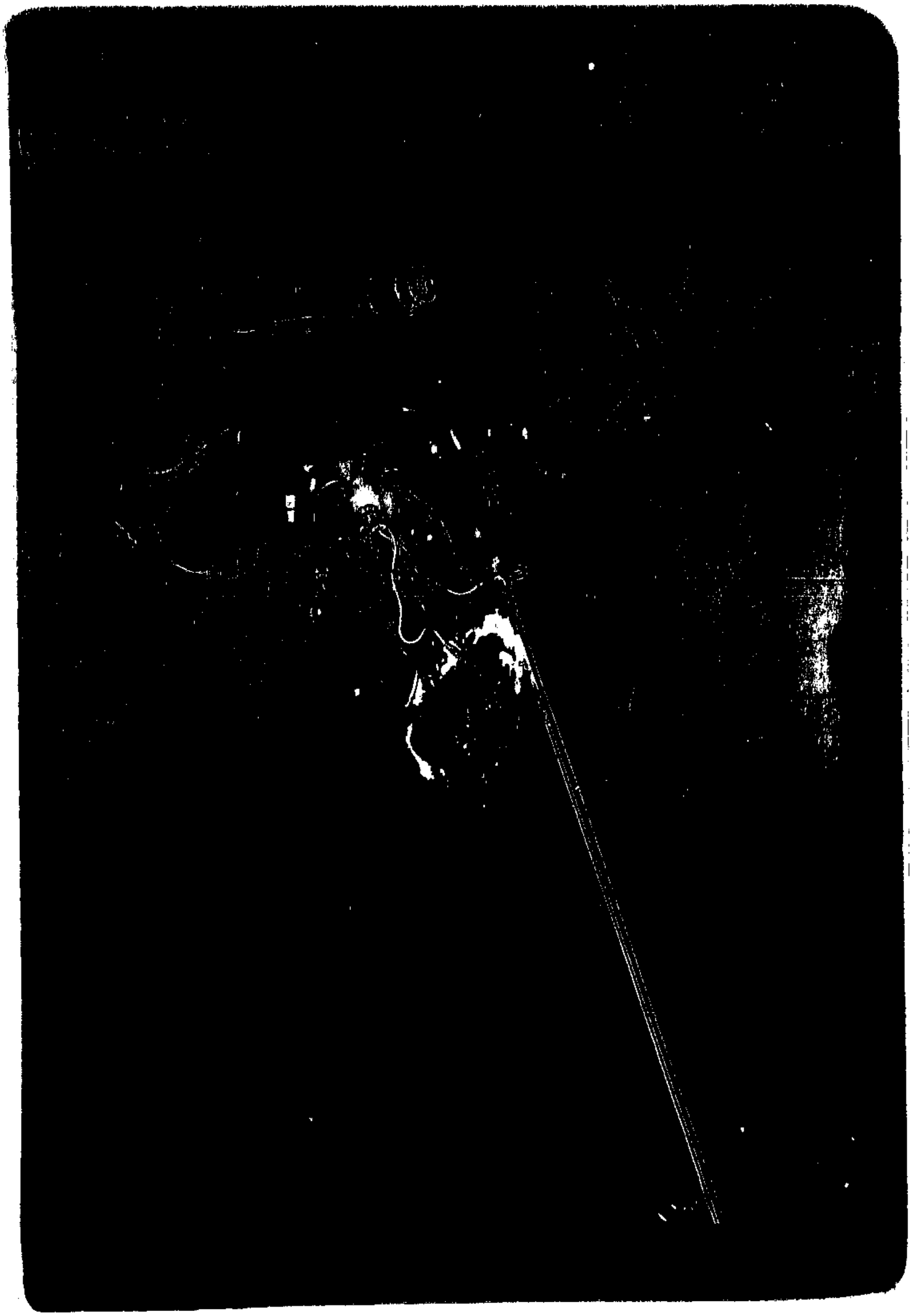

Figure 9. Deflection gage.

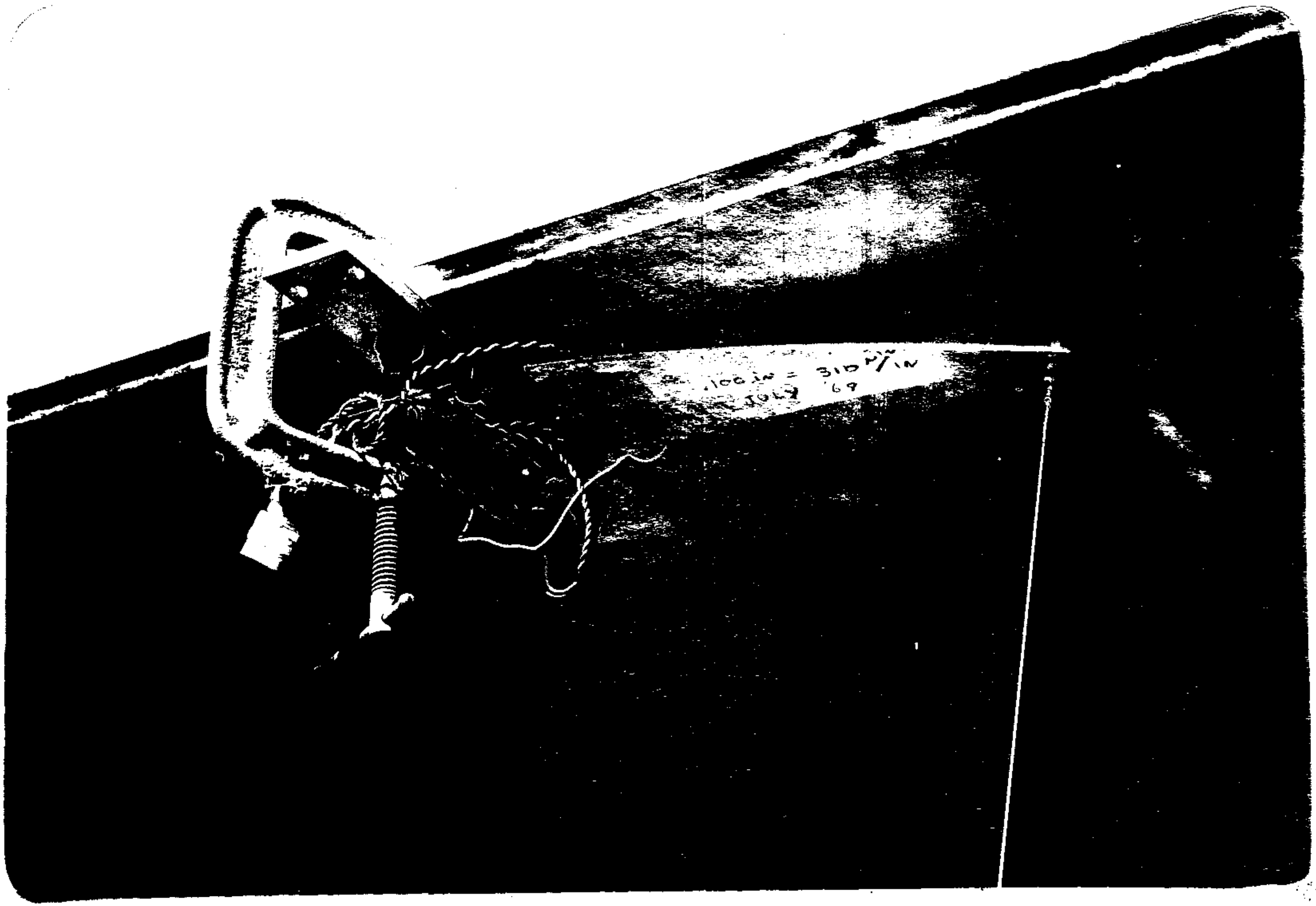

Figure 10. Deflection gage mounted to beam.

producing a corresponding decrease in the measured strains. A permanent record of the change in strains is recorded on magnetic tape simultaneously with other data.

Accelerometers

In addition to strain information and deflection data, acceleration data are compiled during the bridge tests by placing accelerometers at strategic locations on selected bridge superstructures. The accelerometers purchased for this study were selected to serve a dual purpose. Another bridge research study which is being conducted by the Illinois Department of Transportation requires the measurement of the accelerations of piles during driving. Therefore, the accelerometers selected were considered suitable for instrumenting both bridge superstructures and piles. The accelerometer selected was the Endevco Model No. 2261CA-2500, which has a minimum range of from +2500g to -2500g, and is capable of measuring sinusoidal accelerations up to 4000 cycles per second with an accuracy of ± 5%.

Instrumentation Procedures

The collection of accurate and reliable data throughout the duration of the experiment is largely dependent upon the employment of proper strain gage installation techniques and the use of suitable materials for the particular application. The method used to install the gages can be divided into four basic steps as follows:

(1) Surface preparation - Prior to installing the gages the surface to be instrumented must be properly prepared and cleaned. The initial grinding and smoothing of the steel bridge members are accomplished with a portable electric disk sander. For the removal of paint and the initial surface grinding, a No. 60 grit sanding disk is used. After the paint is completely removed, additional grinding is accomplished with a slightly

finer No. 80 grit sanding disk. The surface is then smoothed with a No. 120 grit disk before the final polishing is accomplished by hand with a No. 240 grit sanding tape. After sanding and polishing, the surface is thoroughly cleaned with methyl ethyl ketone (MEK), and guidelines for orienting the gages are marked on the surface with a straightedge and a ball point pen.

(2) Attachment of gage - The gages are attached to the steel surface by first lining up the gages with the guidelines marked on the surface of the bridge member and by hingeing the gage to this surface with a strip of masking tape placed along one side of the gage. The gage is then rotated downward for cleaning with MEK prior to the application of cement. Eastman 910 cement is used for bonding the gage to the steel surface. The 910 cement is a two-component adhesive consisting of the bonding agent and a catalyst which causes the adhesive to set up in just a few seconds. The adhesive is applied to the back of the gage and the catalyst is applied to the steel surface. The gage is then rotated upward and pressed against the surface. Pressure is applied with a rectangular rubber eraser for one minute, after which the gage is completely bonded to the surface. The gage installation is then checked for a satisfactory bond by connecting a strain indicator to the lead wires and pressing against the gage at several points with the eraser end of a pencil. If the strain indicator needle does not deflect, a satisfactory installation has been achieved; however, a deflection of the needle indicates a void in the bonding material, which requires a replacement of the gage installation.

(3) Hook-up of "dummy" gages - After accomplishing a satisfactory gage installation, the lead wires of the gage or gages are connected to a "dummy" gage configuration to form a full-four-arm Wheatstone bridge for each channel of recorded strain information. The "dummy" gage components are prepared prior to the field tests by bonding strain gages identical to those used on the structure to a steel plate. The purpose of the "dummy" configurations is to compensate for any temperature changes which occur during the tests.

(4) Protection of gages - Once the full Wheatstone bridge is completed, the active gages and their lead wires are waterproofed with BLH Barrier E protective coating. Barrier E is a patch type, polymer system which provides excellent moisture and mechanical protection of the gage installations. The patch consists of a neoprene pad with a pliable polymer compound facing which is easily pressed into place and molded around the gage and lead wires.

Although other type gages and procedures may produce equivalent results, the above described procedures have been very effective in producing a gage installation which is durable and which provides consistently reliable data.

APPENDIX

SPECIFICATIONS FOR ELECTRONIC DATA-ACQUISITION SYSTEM

APPENDIX

SPECIFICATIONS FOR ELECTRONIC DATA-ACQUISITION SYSTEM

IHR-301 LIFE EXPECTANCY OF HIGHWAY BRIDGES - STRESS HISTORY STUDIES

1.0 Scope

The scope of this document covers the description of an initial system which will be used to obtain a strain history of highway bridges. This system shall be capable of simultaneously recording 14 channels of strain information on magnetic tape. The work shall consist of the fabrication and furnishing of an electronic data-acquisition system to acquire strain history data on highway bridge loadings and vibrations. The system shall be furnished as a complete unit in the form of a console which will be installed and housed in an enclosed van trailer. All components within the console shall be protected by removable security panels with locks. The work shall include all labor and materials for fabricating and furnishing the data system as specified herein or as otherwise directed by an authorized representative of the department, hereafter designated as the Engineer. The contractor shall also furnish sufficient technical data, drawings, photographs, and descriptive material to describe completely the natures, sizes, and capabilities of all items offered. The information submitted shall also clearly indicate performance characteristics and describe the operation and characteristics as a whole, and shall include a complete description of the interconnections of the various parts.

The intent of this specification is to describe a general outline of the work to include standard or stock electronic components and accessories that are readily available and/or easily modified for compliance of the contract. Revisions meeting the general requirements for this contract, substitution of materials of quality equal in performance and workmanship, and deviations within tolerable limits are permitted upon written authorization.

Evaluation of equipment to be accepted will be made on the basis of least cost of comparable systems most closely approximating the needs within available finances budgeted for this purchase. The basic components of this system shall consist of a strain gage excitation power source, bridge balance, amplifiers, 14-track tape recorder with 2 edge tracks, and a multi-channel hard copy recorder. This system shall also provide a capability for expansion which will later include the necessary electronic components for 14 additional channels. To accomplish this future expansion, it is necessary that a high degree of compatibility exist between present and future systems. This requirement in compatibility will be a consideration in the final evaluation of comparable systems.

2.0 System

This section describes the operation of the system and defines the minimum specifications of the data-acquisition system.

2.1 Operation

A typical test would be sequenced in the following manner. As a vehicle approaches the bridge, a vehicle detector is activated. This detector can be either a microphone pickup or a photo cell. In either case, when the vehicle detector is activated, a set of contacts starts the automatic timer. The automatic timer starts the tape recorder and maintains this "on" condition for a preselected period of from 2 to 30 seconds. In the period of time before the vehicle reaches the bridge and after the tape recorder has reached full speed, a calibration pulse will be generated and fed to all of the recording channels. When the vehicle enters the bridge, a photo cell is activated and the output of this photo cell is recorded on one of the edge tracks of the tape recorder. As the vehicle leaves the bridge, a second photo cell is activated and the signal is recorded on the same channel but with opposite polarity. As the vehicle passes over the bridge, information from the transducers will be recorded on the desired channels. During the entire period a crystal-controlled clock generates a signal which is fed into one of the channels for timing. From the time the recording system is turned on to the expiration of the preselected timing cycle, all 14 channels, plus the two side channels, are recorded.

As the vehicle arrives at the bridge, one photo cell is activated and produces a timing mark on one of the recording channels. As the vehicle leaves the bridge, a second photo cell sensor produces a second timing mark on the same channel so that the speed of the vehicle can be ascertained.

2.2 System Electrical Specifications

This section describes the technical specifications of the system.

2.2.1 Transducers

The transducers will be a full bridge with four 120 ohm strain gages. Two gages will be active and two will be dummies. The gage factor will be 2.0. These transducers are not part of this document, but are included for reference only.

2.2.2 Channels

The number of operational channels shall be 14, plus 2 edge channels for the magnetic tape recorder and at least 12 data channels plus 2 edge channels for the oscillograph. Galvanometers shall be provided for 7 of the main data channels of the oscillograph.

2.2.3 Total Amplification

The system shall be capable of producing a full-scale deflection in both the magnetic tape recorder and the visual recorder when a change of 50 micro inches/inch is induced into a medium which is instrumented with 120 ohm strain gages which have a gage factor of 2.0. The strain gages will be wired in a full bridge configuration with two gages active. When measuring this amplification, the excitation to the strain gage bridge will not exceed 5.0 volts D.C. or R.M.S.

2.2.4 Data Bandwidth

Bandwidth of the system shall be from 0 to 20 KHZ from the transducer through the magnetic tape recorder. The oscillograph shall have a frequency response of 0 to 2 KHZ.

2.2.5 Strain Gage Excitation

The excitation of the transducers shall be DC, and shall be compatible with the strain gage amplifiers used. The excitation for each transducer shall be adjustable from 1.5 V to 11.0 D.C. or R.M.S.

2.2.6 Control

All equipment such as tape recorders and oscillographs shall be capable of operating from remote control as well as local control.

2.2.7 Modular Construction

Major components of the system shall be modular in construction to facilitate easy field replacement or repair.

2.2.8 Primary Power

All components of the system shall operate within specifications from a supply which may vary between 105 and 130 VAC, 60 $\pm$ 10 HZ during operation. The primary power source is not part of this specification.

2.2.9 Calibration

An electrical calibrate button shall be provided for manual calibration of all 14 channels. The calibration shall be accomplished by applying a change of resistance in one or more of the arms in the strain gage transducer.

2.3 System Mechanical Specifications

This section describes the mechanical specifications of the system.

2.3.1 Housing

The system shall be housed in a transportable trailer furnished by the State of Illinois.

2.3.2 Equipment Mechanical Configuration

The equipment shall be housed in a console to be furnished by the contractor as part of the system. The console shall be provided with sufficient rack space to accommodate additional equipment in order to expand the system to 28 channels. All equipment shall be mounted in rack space above desk height. The lower part of the console shall be equipped with drawers for storage space. Painted aluminum blank panels shall be provided for all rack space not utilized by equipment called for in this system. Bidders shall submit a drawing of the console, showing major dimensions and the proposed panel layout of equipment and expansion rack space.

2.3.3 Vibration

The system shall be constructed in a manner that normal vibration of the system encountered during transportation shall not impair the operation of the system.

2.3.4 Placement

The console specified in Section 2.3.2 and entrance panel specified in Section 3.1 shall be mounted in place by State of Illinois personnel.

2.3.5 Security

Locking security panels shall be provided for protecting the console from damage or operation by unauthorized personnel. The panels should be constructed so that they may be easily removed for operation.

3.0 Equipment Specifications

This section describes the minimum specifications for each individual piece of equipment contained within the system and specifies the number of items of each component to be furnished by the contractor.

3.1 Entrance Panel

The entrance panel (1 each) shall have the following:

3.1.1 Strain Gage Connectors

32 environmental-resistant, 7-in., single-turn, quick-disconnect type, Amphenol-type 67.02E14-7S or equal, with 32 appropriate mating cable-connectors, and 32 dust caps with chains.

3.1.2 Intercom Connector

2 each environmental-resistant, 4-pin connectors for use with optional intercommunications system with 2 dust caps and chains.

3.1.3 Photo-Cell Connectors

3 photo-cell and 3 light-source connectors with a minimum of 5 pin-connectors similar to the connectors described in paragraph 3.1.1 for use as photo-cell/light-source sensor-connectors, with 4 appropriate mating cable-connectors, and 4 dust caps with chains.

3.1.4 Size

The entrance panel shall be 32" x 32" of 1/8" aluminum, treated to resist corrosion.

3.1.5 Mounting

The panel shall have provisions for mounting to the side of the trailer with sufficient shake-proof fasteners. A watertight gasket shall be provided between the panel and the trailer. The connectors shall not extend more than 1 3/4" from either side of the panel.

3.1.6 Grounding

The panel shall be in good electrical contact with the trailer and console.

3.2 Photo Cell

Three photo-cell units shall be furnished in accordance with the following specifications:

3.2.1 Size

The photo cell shall not exceed 9 inches in diameter, including the light-gathering lens.

3.2.2 Height

The centerline of the photo cell shall be adjustable from a height of 3" above ground to a maximum of 12" above ground.

3.2.3 Ambient Light

The photo cell shall operate in a range from bright sunlight to complete darkness. A control will be provided to adjust sensitivity with varying ambient light levels. Black-light filters shall be provided for each photo cell. Photo cells shall be capable of operating without adjustment during changes in ambient light from bright sunlight to heavy cloud cover.

3.2.4 Distance

The photo cell shall operate satisfactorily over a distance of 100 feet from the light source.

3.2.5 Operation Light

An indicator light shall be provided on the photo-cell housing that shall operate when the light source is properly aligned.

3.2.6 Controls

All controls--light source on and off, photo cell on and off with sensitivity adjustment, and indicator light--shall be contained in the timing-control panel described in paragraph 3.4.

3.2.7 Environment

The photo-cell unit shall be enclosed in a weathertight enclosure so as to function properly in temperatures from 0° to 120°F and from 0% to 100% humidity.

3.2.8 Response Time

The photo cell shall be capable of operating at interruption rates up to 100 per second.

3.3 Light Source (Photo Cell)

This paragraph describes the light-source units to be used in conjunction with the photo-cell units described in paragraph 3.2. Three light-source units shall be furnished by the contractor.

3.3.1 Size

The light source shall not exceed 9" in diameter, including the collimating lens.

3.3.2 Height

The centerline of the light source shall be adjustable from a height of 3" above ground to a height of 12" above ground.

3.3.3 Ambient Light

The light source shall be sufficient to operate as per paragraph 3.2.3. Black-light filters shall be provided for each light source.

3.3.4 Power Requirements

Light source shall be fed from power source isolated from ground.

3.3.5 Distance

The light source shall operate the photo cell satisfactorily from a distance of 100 feet.

3.3.6 Controls

Controls on the light source are not required.

3.3.7 Environment

The photo-cell light source shall be enclosed in a weathertight enclosure so as to function properly in temperatures from 0° to 120°F and from 0% to 100% humidity.

3.4 Timing Control Unit

One timing-control unit shall be furnished in accordance with the following specifications:

The timing-control unit shall be actuated by the vehicle-detector sensor or photo cell and the timing-control unit shall activate the tape recorder and oscillograph.

3.4.1 Timer

The timing-control unit shall be adjustable from 2 to 30 seconds. The timer shall start and stop the tape recorder and shall delay the "on" and"off" time for the recording oscillograph to compensate for the lag caused by spacing of the playback heads. The accuracy of the timer and the oscillograph delay will be 5% or better.

3.4.2 Calibration Pulse

The timer-control unit shall produce a four-step calibration pulse which will activate all 14 strain gage conditioners. The timer-control unit shall have provisions for activating 14 additional strain gage conditioners for future expansion of the system.

The calibration pulse duration will be adjustable from the front of the panel. Two controls shall be furnished for setting the time to the start of the calibration pulse and the second control to set the total width of the pulse as shown in Figure 4. Both of the controls will be adjustable from 0 to 5 seconds.

3.4.3 Transport Control

The timing-control unit shall furnish to the tape recorder the necessary start and stop signals.

3.4.4 Oscillograph Control

The timing-control unit shall be capable of furnishing to the oscillograph the necessary start and stop signals for the chart drive. An adjustable delay shall be provided for the lag caused by the spacing of the playback heads.

3.4.5 Calibration Voltage and Switching

The timing-control unit shall furnish to the gage-control unit described in paragraph 3.6 the necessary signals to calibrate each set of strain gages.

3.4.6 Inhibit

On the front of the timing-control panel an inhibit button will be provided. When this button is depressed, it will stop the timing cycle and reset the timer.

3.4.7 Manual or Automatic Switching

A switch shall be provided for over-riding the automatic timing feature. Manual position shall provide continuous operation of system.

3.4.8 Primary Power

The primary control unit shall provide all the power for the system and shall consist of an appropriate circuit breaker and indicator lamp. The circuit breaker shall be

3.5 Clock Unit

3.5.1 One clock unit with a crystal-controlled generator marker shall be furnished in accordance with the following specifications:

3.5.1.1 The accuracy of the clock shall be 0.001% or greater.

3.5.1.2 A frequency-selector switch shall be provided. This switch shall permit selection of four frequencies, 1 HZ, 10 HZ, 100 HZ, 1000 HZ.

3.5.1.3 The output of the clock will be a square wave with 1-volt P.P. or greater with a 50-50 duty cycle.

3.6 Bridge Balance Unit

Fourteen bridge balance units shall be furnished by the contractor in accordance with the following specifications:

3.6.1 Controls

3.6.1.1 Excitation Control

Excitation voltage shall be controlled over the range of 1.5 to 11.0 volts. Control shall be by a ten-turn potentiometer with locking knob. Each gage shall be provided with separate excitation control. Excitation voltage shall be available on the front panel.

3.6.1.2 Balance

Balance shall be controlled by at least one ten-turn potentiometer with locking know. Each gage shall be provided with separate balance. Balance voltage shall be available on the front panel. The balancing unit shall have a balancing range of $\pm$ 10,000 u in./in. with a fine balance to 1 u in./in.

3.6.1.3 Calibration

Four-point calibration shall be provided as shown on Figure 4, with the calibration impulses generated from the timing-control unit. Calibration shall be accomplished by applying known resistances across the arms of the bridge.

3.6.1.4 Output Control

The output shall be switchable from reverse polarity, shorted, and normal position to facilitate base-line adjustments.

3.6.1.5 Transducer Cabling

The bridge balance unit shall have provisions for 6-wire cabling from the transducers.

3.6.2 Excitation Source

The excitation source shall be D.C. and shall be compatible with the strain gage amplifiers used in the system. The excitation source may be either a single source or one source for each strain gage amplifier. If a single source is used, it must be capable of exciting 28 transducers and meet all the requirements listed in this section when up to 13 strain gage transducers are shorted when applying 5 volts to each transducer.

3.6.2.1 Excitation Output

Adjustable from 0 to + 12 volts or greater.

3.6.2.2 Line Regulation

0.01% for a line voltage change of $\pm$ 10%.

3.6.2.3 Load Regulation

0.02% from no load to full-rated load.

3.6.2.4 Temperature Coefficient

0.001% per degree F.

3.6.2.5 Ripple

Less than 1mv P-P.

3.6.2.6 Cross Talk

Cross talk between channels shall not be greater than 1 u in.

3.6.3 Environmental

3.6.3.1 Operating Temperature Range

0^{o}C to 50^{o}C (32^{o}F to 122^{o}F).

3.6.3.2 Humidity

95% maximum RH.

3.6.4 D.V.M. Display

A means for remote sensing by push buttons shall be provided for display of the excitation voltage and of the output voltage of each strain gage amplifier on the D.V.M.

3.7 Strain Gage Amplifier

Fourteen strain gage amplifiers shall be furnished in accordance with the following specifications:

3.7.1 Performance

3.7.1.1 Input

The input shall conform to the requirements specified in paragraph 2.2.3.

3.7.1.2 Gain

The gain shall conform to the requirements specified in paragraph 2.2.3.

Range - At least 6 steps of attenuation with vernier control.
Accuracy - Shall be $\pm$0.5% at DC.
Stability - Shall be less than .1%/^{o}C.
Linearity - Shall be better than 0.2% of full-scale output.

3.7.1.3 Frequency Response

$\pm$ 2% DC to 20 KC.

3.7.1.4 Phase Shift

Less than 10 degrees from DC to 20 KC.

3.7.1.5 Drift

Less than 5 micro volts referred to input for a 24-hour period.

3.7.1.6 Common Mode Characteristics

Voltage - $\pm$ 10 DC or peak AC.
Rejection - Greater than 85 db from DC to 400 HZ.

3.7.1.7 Output

The output of the amplifier shall be sufficient to drive the galvanometer as described in paragraph 3.11.3 when it is desired to operate the system bypassing the magnetic tape unit.

3.7.1.8 Power Requirements

120 VDC - 60 HZ - 20 watts max.

3.7.2 Controls

The amplifier shall have the following controls:

3.7.2.2 Gain Control

Fine and coarse controls.

3.7.2.3 Output Switch

A switch will be provided for shorting the input of each strain gage amplifier.

3.7.3 Environmental

3.7.3.1 Temperature Range

$0^{o}C$ to $50^{o}C$ ($32^{o}F$ to $122^{o}F$).

3.7.3.2 Humidity

95% maximum RH.

3.8 Tape Recorder

This section describes the technical specifications of one 14-channel tape recorder with 2 edge tracks to be furnished by the contractor.

3.8.1 Tape Transport and Drive

3.8.1.1 Tape Speeds

Standard tape recorders with 6 speeds ranging from 15/16 ips to 60 ips are acceptable. Tape speeds of 15/16, 1 7/8, 3 3/4, 7 1/2, and 60 ips are preferred.

3.8.1.2 Speed Accuracy

The tape speed shall be accurate to within $\pm$ 0.25% when servoing from capstan.

3.8.1.3 Reels and Tapes

The transport shall accommodate 3" NAB hole-size precision reels with reel diameters not less than 10 1/2" of 1" magnetic tape. Two reels of magnetic tape on precision reels shall be furnished with the recorder.

3.8.1.4 Tape Start-Stop Time

Tape start and stop shall be 10 seconds or less for any speed.

3.8.1.5 Inter-Track Time Displacement Error

The ITDE shall not exceed 3 micro-seconds measured between outside tracks on the same 1" head stack at 60 inches per second.

3.8.1.6 Flutter

Flutter shall not exceed 0.6% peak to peak, 0.2 HZ to 10 KHZ at 60 ips.

3.8.1.7 Controls

Front panel controls shall be provided for speed selection, power rewind, record, stop, drive forward, fast forward.

3.8.1.8 Tape Heads

1", 14-track, recording and reproduce heads with edge tracks shall bè included and conform to applicable provision of IRIG-106-66.

3.8.1.9 Servo Speed Control System

A phase-lock servo speed control utilizing a 100 KHZ reference frequency at 60 ips and proportional at other speeds per IRIG-106-66 to control capstan speed during record and for recording for playback reference shall be included. Reference frequency shall be accurate to within ± 0.03%.

3.8.2 FM Record/Reproduce Electronics

3.8.2.1 FM Record Electronics

14 channels of 40% deviation FM Record channels shall be provided. All center frequencies shall be electrically switched by front panel. Center frequencies shall be per IRIG-106-66. Full 40% deviation shall be obtained with a 1-volt peak signal. Input impedance shall be 20K ohms or greater. Linearity shall be ± 0.5% or less. The recorder shall be capable of recording on all 7 speeds specified in paragraph 3.8.1.1.

3.8.2.2 FM Reproduce Electronics

14 channels of FM reproduce electronics shall be provided for the four lowest speeds of the tape recorder. Center frequencies shall be per IRIG-106-66 and frequency response shall be per IRIG-106-66; signal-to-noise ratio 1 7/8 ips shall be 40 db or better.

Harmonic distortion shall be 1.5% or less.

Linearity shall be ± 0.5% or less over 50^{o}F to 0^{o}F for a 10-day period.

3.8.3 Environmental

3.8.3.1 Power

Power requirements shall be 105 to 130 VAC, 60 ± 10 HZ.

3.8.3.2 Temperature Range

0^{o}C to 50^{o}C (32^{o}F to 122^{o}F).

3.8.3.3 Humidity

95% maximum RH.

3.8.3.4 Size

19" rack-mounted

3.8.4 Calibration

Frequency control and calibration shall be provided.

3.8.5 Audio Record and Monitor System

An audio system shall be furnished which will allow voice information to be recorded and/or monitored on any of the 14 channels or the edge tracks. The system shall consist of a microphone, amplifiers, and one set of headphones. The audio system shall be capable of providing signals for recording and monitoring on any channel simultaneously. A jack shall be provided as specified in paragraph 3.10 on the patching panel to allow the microphone and headphones to be plugged into any of the 14 channels or edge tracks.

3.8.5.1 Microphone

The microphone shall be a low impedance, noise-canceling type. Two sets of microphone input connectors shall be provided. One input connector shall be located on the entrance panel. The second input connector shall be located on the console.

3.8.5.2 Amplifiers

A microphone amplifier shall be provided to sufficiently drive the input of the tape recorder. An amplifier, if necessary, shall be provided to sufficiently drive the headphones from the output of any of the 14 channels or edge tracks of the tape recorder.

3.8.5.3 Headphones

The headphones shall be capable of monitoring the audio input of the tape recorder or the playback heads of the recorder.

3.9 Patch Panel

A patch panel shall be provided to patch the inputs and outputs of the tape recorder, as desired, to the inputs of the galvanometers. The patch board shall have provisions for bypassing the tape recorder.

3.9.1 Signal Levels

The signal levels at the tape recorder input and the tape recorder output patch panel terminals will be approximately equal in amplitude so that no gain adjustments would be necessary when patch channels are made.

3.10 Oscillograph

One oscillograph shall be furnished in accordance with the following specifications:

3.10.1 Number of Channels

Twelve data channels or more, plus two edge channels, shall be available. A minimum of seven galvanometers shall be furnished. See paragraph 3.9 for patching.

3.10.2 Paper

Paper used shall be direct printout paper. No chemical shall be needed to develop the trace. The width shall be no less than 7" and at least 100 ft/roll. A carton of 24 rolls of paper shall be furnished with the recorder.

3.10.3 Galvanometers

The galvanometers shall have the following characteristics:

3.10.3.1 Frequency Response

Shall be 0 to 200 HZ or more, flat (± 5%).

3.10.3.2 Deflection

Each galvanometer shall be capable of full-scale deflection as per section 2.2.3 when driven from any of the recorder inputs or outputs on the patching panel. A means shall be provided for adjusting the deflection of each galvanometer from zero to full scale.

3.10.3.3 Linearity

± 2% of full scale.

3.10.4 Controls

The oscillograph shall have the following controls.

3.10.4.1 Recording Galvanometer Trace Intensity

3.10.4.2 Grid Line Intensity

3.10.4.3 Time Line Control

3.10.4.4 Power On-Off

3.10.4.5 Paper-Speed Selector

Push-button selectable of at least 8 speeds in the range of 0.4 to 80 ips.

3.10.5 Trace Identifier

A trace identifier shall be included in the oscillograph.

3.10.6 Remote Operation

Provisions will be made for remote operation of power, lamp start and chart drive.

4.0 Accuracy of Total System

The accuracy of the total system shall be measured as the ratio of the error to the full-scale output expressed as a percent.

The accuracy of the total system from the input of the transducers to the recorded output shall be as follows:

Recorded Data on Magnetic Tape ± 3%.

Recorded Data on Oscillograph through the Magnetic Tape Unit ± 5%.

The contractor shall furnish documented evidence demonstrating the operational performance of the overall system. The contractor shall also furnish written certification that the system conforms to the requirements stipulated herein and demonstrate to the Engineer's satisfaction that the overall system fulfills these requirements.