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INSTRUMENTATION FOR MEASUREMENT OF COUPLING FORCES IN ROAD TRAINS

by

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AUSTRALIAN ROAD RESEARCH BOARD INTERNAL REPORT

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REPORT SUMMARY

THE PURPOSE OF THIS REPORT

is to document and describe the specialised equipment developed by ARRB for the measurement and recording of tow coupling force data in a road train.

THIS REPORT SHOULD INTEREST

those involved n the measurement of data in vehicles, particularly in harsh conditions and limited-opportunity testing.

THE MAJOR CONCLUSIONS OF THE REPORT ARE

that the successful development of force transducers from tow coupling eyes, together with a mobile data acquisition system, enabled the measurement of hitch force data in limited-opportunity testing under harsh operating conditions.

AS A CONSEQUENCE OF THE WORK REPORTED, THE FOLLOWING ACTION IS RECOMMENDED

that the microprocessor data analyser be applied in other similar vehicle studies.

RELATED ARRB RESEARCH

P264 Dynamic truck suspension performance

A830 Assistance to NAASRA Road Train Working Party

CUT OUT INFORMATION RETRIEVAL CARD...........

GEORGE, R.M. (1980) : INSTRUMENTATION FOR MEASUREMENT OF COUPLING FORCES IN ROAD TRAINS. Australian Road Research Board. Internal Report AIR 1083–2. 34 pages, including 2 tables, 19 figures.

KEYWORDS : Articulated vehicle/lorry/trailer/large combination vehicle*/apparatus(measuring)/strain gauge/transducer/data acquisition/microprocessor*/magnetic tape/coupling/force

ABSTRACT : A system has been developed by ARRB for the measurement, recording and analysis of tow coupling force data on large combination vehicles (road trains). The data was required as a basis on which to formulate a method of calculating the strength ratings of couplings under Australian conditions. This report describes (i) the development and calibration of the transducers and (ii) the associated instrumentation including a microprocessor based data analyser. The transducers were strain gauged 50 mm draw-bar eyes calibrated to measure longitudinal forces acting between the units in the road train. The microprocessor based analyser permitted hitch force distributions to be printed out during the road test which took place between Port Augusta, South Australia and Alice Springs, Northern Territory. Complete records of hitch forces in both a double (prime mover and two trailers) and a triple (prime mover and three trailers) were obtained on magnetic tape for subsequent analysis.

*Non IRRD Keywords

CONTENTS

ABSTRACT

A system has been developed by ARRB for the measurement, recording and analysis of tow coupling force data on large combination vehicles (road trains). The data was required as a basis on which to formulate a method of calculating the strength ratings of couplings under Australian conditions. This report describes (i) the development and calibration of the transducers and (ii) the associated instrumentation including a microprocessor based data analyser. The transducers were strain gauged 50 mm draw-bar eyes calibrated to measure longitudinal forces acting between the units in the road train. The microprocessor based analyser permitted hitch force distributions to be printed out during the road test which took place between Port Augusta, South Australia and Alice Springs, Northern Territory. Complete records of hitch forces in both a double (prime mover and two trailers) and a triple (prime mover and three trailers) were obtained on magnetic tape for subsequent analysis.

ACKNOWLEDGEMENTS: The author wishes to express thanks to Gitsham Transport Engineers for donating three VBG eye couplings, Bruce McDonald of McDonald Transport for his co-operation and generous assistance and the driver of the road train Mr. R. Blott.

1. INTRODUCTION

The Standards Association of Australia formulated and published an Australian Standard 'AS 2213-1978 50 mm DIN Type Couplings for Trailers' in 1978, for the strength rating of couplings used on road trains. This standard was based on a European DIN standard known as the 'D' rating, which governs the manufacture of most couplings currently used in Australia and applies to combinations of two units only.

Some Australian road train operators questioned the applicability of this European standard to their vehicles comprising more than two units. Ultimately the National Association of Australian State Road Authorities (NAASRA) commissioned the Australian Road Research Board (ARRB) to undertake research to measure actual in-service hitch forces on road train couplings, whilst travelling on existing routes, and recommend a method of calculating strength ratings.

This report describes the specialised equipment developed by ARRB for the measurement and recording of two simultaneous channels of hitch force data acquired on a journey from Port Augusta, South Australia to Alice Springs, Northern Territory.

1.1 SYSTEM OVERVIEW

An entire system was developed for hitch force measurement and recording. As there was no documentation available of previously acquired hitch force data for a road train of the size shown in Fig 1, the magnitude of force levels was unknown, so a flexible system was required with the capability of measurement up to the 'D' rating of couplings used. (VBG-881 50 mm couplings with a 'D' rating of 16 t were used.) At the same time, a high degree of experimenter access to the data during the journey was required to ensure that useful data was being obtained because, unlike other forms of experimental research, the test could not be repeated readily.

The in-service hitch force measurements were carried out in two stages, firstly as a 'triple' (that is, a prime mover with three trailers), measuring and recording data from two couplings, and secondly as a 'double' (that is a prime mover with two trailers) measuring and recording data from one coupling. These measurements were achieved with the generous co-operation and assistance of McDonalds Transport (SA) who operate a regular haulage service form Adelaide to Darwin.

Force transducers were developed from 50 mm coupling eyes, and inserted into the appropriate towing frames. Signal conditioning amplifiers were also mounted on the towing frames (Fig 2) in close proximity to the transducers, and multi-core electrical cables were taped to the top of the trailers, providing power and signal connection.

All hitch force data was recorded in analog form on magnetic tape, and simultaneous real time data analysis was performed by an on-board microprocessor. The signal conditioning circuitry, magnetic tape recorder and power supplies were mounted in a specially designed shock and vibration absorbing housing (Fig 3) which was located in the sleeper cab immediately behind the driver. A remote control was provided and this enabled the operator, in the passenger's seat, to start and stop data acquisition as required. The operator's description of the road conditions and landmarks was recorded on a voice track of the magnetic recorder and this was invaluable when collating data in the laboratory.

2. HITCH FORCE MEASUREMENT

The physical and mechanical constraints of the couplings, along with the requirement to exchange the measuring devices under difficult outback conditions, prohibited the use of commercially available force measuring devices. It was therefore necessary to apply strain sensing elements to standard coupling eyes, and calibrate them for force measurement. These bolt-on coupling eyes with straight-sided shanks lent themselves to this application. The Australian agents for VBG, Gitsham Transport Engineers (SA), supplied three VGB-881 50 mm coupling eyes.

2.1 TRANSDUCER DEVELOPMENT

The construction of the VGB-881 50 mm coupling eye was suitable for adaptation into a single axis bi-directional force transducer. This was quickly assessed by initially applying three strain gauges longitudinally distributed along the shank and acting in the sensitive axis (Fig 4). This strain gauged coupling was mounted in ARRB's Electro Hydraulic Closed Loop Material Testing System (MTS), and the individual electrical outputs of each strain gauge were amplified, monitored and recorded whilst the coupling was subjected to static tensile and compressive forces of up to 150 kN in 10 kN increments. Amplified strain gauge outputs were plotted against applied force and inspected for linearity and symmetry (Fig 5). An acceptable position for the strain gauges, based on obtaining equal sensitivity in tension and compression, was found to be around gauge No. 2 located 123 mm from the machined edge of the flange (Fig 4). The coupling eye was then strain gauged, with Micro Measurements WK-06-125BT-350 gauges. On each side of the coupling shank, a strain gauge was mounted with its sensitive axis parallel to the longitudinal axis of the coupling. Two 'dummy' gauges were attached with their sensitive axes normal to the longitudinal axis of the coupling. The four strain gauges were connected in a full bridge configuration (Fig 6).

2.2 TRANSDUCER EVALUATION

A series of tests was conducted to evaluate the performance and calibration of the system consisting of the strain gauged coupling eye force transducer together with its signal conditioning amplifier.

(a) Sensitivity

As in the preliminary evaluation, the MTS (Fig 7) was used to apply calibrated forces within the range ±150 kN in 10 kN increments (tensile forces are designated positive), and the corresponding amplifier output recorded. (Table I).

The output of the strain gauged bridge was amplified by an ECTRON 314A, extreme environment sub-miniature amplifier with a nominal gain of 1000. The amplifier was biased to produce an output of approximately 2.5 volts with zero strain (see section 3.1 (c)). The amplifier output was plotted against applied force (Fig 8), and a linear regression program (least squares method) was applied to the data pairs to compute a 'line of best fit' describing the relationship between applied force and amplifier output. The expression was:

$$F(kn) = 82.17V-202.4 \qquad (1)$$

The coefficient of correlation (r^2) was 0.99.

At the maximum applied force of 150 kN a longitudinal strain in the coupling of approximately 310 $\mu\varepsilon$ was measured.

(b) Linearity

From Table I, the largest deviation in either direction of any plotted data point from 'line of best fit' was +0.007 V and -0.033 V. Expressing these as percentages of full scale output, the deviations from linearity are 0.16 per cent and -0.77 per cent full scale.

The Ectron amplifier linearity is quoted as 0.05 per cent.

(c) Hysteresis

This is defined as the zero output offset following an increase to full scale and return to zero, expressed as a percentage of full scale:

Initial zero = 1.500 V

Zero after full scale = 2.490 V

Full scale output = 4.282 V

$$\text{Hysteresis} = \frac{(2.500 - 2.490)}{4.282} \times \frac{100}{1} = 0.23 \text{ per cent.}$$

(d) Cross Axis Coupling Sensitivity

This is defined as the apparent transducer input per unit cross axis input. A test was performed as depicted in Fig 9. A cross axis force of 18.61 kN was applied 330 mm from the towing pin on the longitudinal centre line, and produced an electical output of 2.68 V, which is equivalent to an apparent transducer force of 17.8 kN, therefore the cross axis coupling sensitivity is 0.96 kN/kN. Although this is a very high cross axis sensitivity the mass of the towing frame is relatively small and such errors were estimated to be less than 4 per cent of the peak longitudinal force measured and less than 2 per cent of the full scale calibrated longitudinal force.

(e) Temperature Coefficient

A test was performed by measuring the amplifier output at room temperature (23°C) and then placing the strain gauged coupling eye, with the Ectron amplifier, in a temperature-controlled oven with a stabilised temperature of 37°C. The amplifier output was measured when the system stabilised at the elevated temperature.

Ectron Amplifier Output (Volts)	Temperature (°C)
2.493	23
2.520	37

Temperature Coefficient (assuming linearity) = Per cent change in output per unit temperature rise

$$= \frac{\frac{2.520 - 2.493}{2.493}}{37 - 23} \times 100$$

$$= 0.077 \text{ per cent/°C}$$

(f) Non-repeatability

This is a defined as the ability to produce the same output for the same given input, expressed as percentage of full scale. This parameter was evaluated at an applied force level of +130 kN. The initial amplifier output was 4.043, and the repeated value was 4.032.

$$\text{Non-repeatability (assuming linearity)} = \frac{4.043 - 4.032}{4.282} \times 100 = 0.26 \text{ per cent.}$$

2.3 ACCEPTANCE

The strain gauged VBG-881 50 mm coupling eye which has a 'D' rating of 16 t, was calibrated to measure hitch forces within the range of ±150 kN to accuracies as previously described. The strain gauged coupling eye was considered to be adequate for the investigation, and three such transducers were produced.

2.4 TRANSDUCER ENVIRONMENTAL PROTECTION

In view of the anticipated harsh operating environment, moisture and mechanical protection of the strain gauges was applied. This was achieved in two stages. Firstly Micro Measurements protective coatings were applied as follows:

(a) Air drying Polyurethane Coating (M-coat A)

(b) Butyl Rubber Sealant (M-coat FB-2)

(c) Neoprene Rubber Sheets (M-coat FN-2)

(d) Adhesive Aluminium Foil Tape (M-coat FA-2).

Secondly, shields made from 1.6 mm aluminium sheet were fabricated so as to completely surround the already-applied protective compounds. These shields were fastened with Panduit Self locking nylon cable ties, (Fig 10) and exposed joints and ends were sealed with Silastic Silicon Rubber.

3. TRANSDUCER SIGNAL CONDITIONING

The heart of the instrumentation system was the Ectron extreme environment amplifier model 314A (Fig 11), a sub-miniature solid state differential DC amplifier, mounted in a 16.5 cm^3 encapsulated metal case.
The extreme environmental characteristics of the 314A enabled its housing to be mounted directly on the towing frame, and hence in close proximity to the strain gauge bridge. The Ectron 314A amplifier requires a single power supply, derives the strain gauge bridge excitation internally, and is protected against electromagnetic interference for both power and signal leads. (For environmental specifications refer Table II).

3.1 ECTRON 314A INSTRUMENTATION AMPLIFIER SUB-SYSTEM (Fig 12)

(a) Input

The differential inputs were tied to 0V, with two 100 kΩ resistors. This was to ensure that the input would maintain an earth reference if the strain gauge bridge was disconnected.

(b) Amplification Factor

The gain was determined by the parallel combination of R_3 and R_4 (Fig 12) according to the formula:

$$\text{Gain} = 1.67 \times 10^5 \frac{R_4 + R_3}{R_4 \times R_3} + 8.33 \qquad (2)$$

with R = 560 Ω and R = 240 Ω

the Gain = 1000.

(c) Output Bias

The maximum output voltage swing was quoted as -0.8 V to +5.8 V. Therefore, to enable the amplification of compressive and tensile force signals, the amplifier output signal was biased to approximately half the total output voltage swing. The biasing was achieved by the connection of resistances between Pins 7 and 6 (Fig 12). Values were determined by the formula,

$$R(\text{OHMS}) = \frac{5.54 \times 10 \ (\text{VBIAS} + 0.2)}{4.73 - (\text{VBIAS} + 0.2)} \qquad (3)$$

The value for VBIAS is independent of the amplification factor.

Five bias voltages, selectable by a front panel control, labelled 'offset voltage', were provided, with nominal values of 0.5, 1, 1.5, 2, 2.5 volts.

(d) Output

The differential output (i.e. not referenced to 0V) was connected to the input of the next stage (active filter) via resistor R5. As the amplifier was mounted on the towing frame, approximately 30 m of electrical cable was required to connect to the recording and analysing equipment located in the truck cab. To avoid the effect of long-line reactive component instability, the input resistance of the next stage was split, R5 being in the order of one eighth of the total input resistance value.

3.2 ACTIVE FILTER AND VARIABLE GAIN SUB-SYSTEM

(a) Active Filter

A two pole low pass active filter (Fig 13) was constructed around a precision operational amplifier (LM308A) with negative unity gain and frequency characteristics of -6db break point at 90 Hz, with a roll-off of 12db/octave. An amplitude versus frequency plot is shown (Fig 14).

(b) Variable Gain

A precision operational amplifier (LM308A) was configured as an inverting amplifier with six selectable gain positions. Nominal gains of 0.5, 1, 2, 2.5, 3.3 and 5 were front-panel selectable. Used in conjunction with Ectron 314A amplifier offset control (paragraph 3.1(c)) maximum flexibility was obtained in accommodating a range of hitch force levels.

4. VEHICLE SPEED MEASUREMENT

A system was developed to measure and record vehicle speed. The measurement device basically consisted of a ten-vane disc (ARRB type 400.1), interrupting the beam between an infra-red light source and a light-sensing element. The disc was rotated by the truck speedometer cable and the light-sensing element produced a number of pulses proportional to rotational speed. These pulses were converted into an analog voltage.

The interruption module was fitted to the rear of the speedometer, allowing the speedometer cable to feed through without loss of speed indication to the driver.

Prior to installation, a calibration figure of 1000 revolutions of the speedometer cable per 1.6 km was applied and verified in the laboratory by attaching the interrupter module to a speedometer of similar manufacture to that used, and rotating the cable with an electric motor.

In order to confirm the calibration on the test vehicle, a fifth wheel speedometer, with an analog output proportional to vehicle speed, was connected to the test vehicle, and its output was also recorded on magnetic tape, while the vehicle was driven a short distance on a smooth road.

5. DATA RECORDING

All hitch data was recorded in analog format, on a Racal seven-track FM Instrumentation ½" magnetic recorder. This recorder was designed to derive its power requirements from vehicles (11-32 VDC) and, most importantly for this application,to operate in harsh environemntal conditions. With a tape transport speed of 1 7/8 IPS, the duration of each tape reel was 4.75 hours.

6. SIGNAL VERIFICATION

A hand-held monitor was provided, enabling the operator to check the presence of the following -

(a) both hitch force signals,

(b) vehicle speed signal,

(c) fifth wheel signal,

(d) ±15 volt power supplies.

A centre-zero taut-band DC meter, capable of displaying in two modes (either DC or RMS) was incorporated, with provision for connection of an external digital meter. The analog meter gave a good indication of steady hitch forces, but was insensitive to dynamic force changes. The digital meter produced rapid updating providing the operator with some indication of instantaneous hitch force data.

7. DATA ANALYSER AND STATISTICAL PROCESSOR

The Data Analyser and Statistical Processor (DASP) (Fig 15) is a microprocessor-based system designed to operate in parallel with the magnetic tape recorder. It is capable of sampling two analog signals simultaneously and computing the following basic statistical functions for each channel.

(a) Probability density histogram, with selectable class boundaries of 16, 32, 64 and 128.

(b) Cumulative probability distribution, actual or percentage selectable.

(c) Mean ($\bar{x}$).

(d) Standard deviation (SD).

The microprocessor could, upon request, pause during data sampling time without loss of acquired data. An alphanumeric printer was incorporated to output the data. It had the ability, when requested, to provide a print-out of force amplitude distributions, whilst still acquiring data. This was useful for the verification of data and examining force trends. Typical print-outs are shown in Figs 16 and 17. A digital display was provided to display elapsed sampling time or the instantaneous amplitudes of the sampled signals, updated every three seconds.

7.1 HARDWARE

The DASP was manufactured by ECOTECH, Melbourne, and is based on INTEL Corporation's single board computer range, using the iSBC 80/20-4 as a central processor unit, iSBC711 analog input board, and an Advanced Micro Devices AM 9511 arithmetic processor unit. These boards were housed in an iSBC604 modular cardcage, and powered by an iSBC635 power supply. The complete unit was mounted in an aluminium attache case, and was located on top of the instrumentation housing secured by elastic straps.

7.2 COMPLETE SPECIFICATIONS FOR DATA ANALYSER AND STATISTICAL PROCESSOR

(a) To sample simultaneously data from two analog channels, and compute the following basic statistical functions for each channel:

- (i) Probability Density Histogram with class boundaries of 16, 32, 64 and 128 selectable,
- (ii) Cumulative Probability Distribution,
- (iii) Mean ($\bar{x}$),
- (iv) Standard Deviation (SD).

(b) Selectable Sampling Rates of:

- (i) 50 samples/second/channel,
- (ii) 100 samples/second/channel,
- (iii) 200 samples/second/channel,
- (iv) 400 samples/second/channel,

(c) Sampling time controlled manually, (i.e. via Front Panel Control) or upon sampling time exceeding 9000 s.

(d) Controls give the following functions:

(i)	POWER ON	:	Applies power and resets run counter,
(ii)	FREEZE	:	Sets reference (as display) for both channels,
(iii)	RESET	:	Clears all existing data,
(iv)	START	:	Starts data acquisition,
(v)	PAUSE	:	Halts data acquisition, but maintains collected data,
(vi)	CONTINUE	:	Continues data acquisition without clearing,
(vii)	HALT	:	Stops data acquisition,
(viii)	PRINT	:	Starts print out,
(ix)	HALT PRINT	:	Stops print out,
(x)	INPUT SENSITIVITY	:	Selects 0-1.25 V, 0-5 V or 0-10 V full scale,
(xi)	MANUAL DATA IDENTIFICATION	:	2 digits,
(xii)	MANUAL GAIN SETTING IDENTIFICATION	:	1 digit.

(e) Print-out format selectable:

(i) Probability density distribution (raw data)

(ii) Probability density distribution histogram bar graph. Automatic scaling with the following symbols.

$ represents 0.5 per cent of total frequency of occurrence

& represents 1 per cent of total frequency of occurrence

% represents 2 per cent of total frequency of occurrence

* represents 4 per cent of total frequency of occurrence.

(iii) Cumulative probability distribution, actual or percentage selectable.

Leading zeros are suppressed. With the exception of (i) class boundaries of 16, 32, 64 or 128 are selectable and a calculated value for mean and standard deviation follows

(f) Preliminary print-out during data acquisition:

All the function in the above para (7.2 (e)) are available but no values for mean and standard deviation are calculated.

(g) Digital display, selectable:

(i) Channel A and Channel B no load data only prior to commencement of acquisition.

(ii) Channel A and Channel B instantaneous amplitudes updated every 3 s.

(iii) Elapsed sampling time in seconds.

(h) Power Supply:

240 V AC at 240 VA

(i) Mounted in an aluminium attache case:

Overall dimensions, W 430 mm x H 200 mm x D 430 mm.

8. POWER REQUIREMENTS

Four levels of power were required, all to be derived from the vehicle's source: +28 volt DC (required to power the Ectron 314A amplifier), ±15 volts DC for the signal conditioning amplifiers, 11-23 volts DC for the magnetic tape recorder and 240 volts AC for DASP. These will be considered in turn.

8.1 +28 VOLT DC (Fig 18)

A DC-to-DC inverter was designed to supply +28 volts DC at one ampere, over the input range of 11-15 volts DC, as the normal battery voltage is within the range 13.8 to 14.2 volts. It was not necessary to regulate this supply as the Ectron 314A had a ±4 volt tolerance and internally regulated power supplies, but a 32 volt zener diode provided crude over-voltage protection.

8.2 ±15 VOLT DC

A commercially available DC to DC inverter (Burr Brown Model 528) provided these voltages to the signal conditioning amplifiers. Its input was supplied from the +28 volt supply. Although this reduced efficiency, the 528 inverters were on hand from a previous application. The regulation was quoted as ±0.1 per cent with ripple less than 20 mVP-P at full load.

8.3 12 VOLT DC

The instrumentation magnetic tape recorder required 11-32 volts DC. As noise and spike suppression was a feature of the recorder, and signal returns were isolated from the power return, it was connected directly to the vehicle's battery.

8.4 240 VOLT AC

The DASP required 240 VAC at approximately 240 VA. An Invertech A12-250 inverter was operated directly from the truck battery and was located on the floor behind the operator's feet.

9. PERFORMANCE

The development of force transducers from tow coupling eyes, enabled the measurement, recording and analysis of two channels of coupling force data. This analysed data provided information for the development of a method of calculating strength ratings for couplings used on road trains.

9.1 TRANSDUCER FAILURE

Although meticulous care was taken to protect the transducers from the harsh environment, one transducer was damaged when attempting to connect the trailers. This was repaired successfully prior to commencement of the journey. Another transducer failed to operate and was replaced with a spare. Subsequent investigation traced the fault to flexible strain gauge lead wires which caused an open circuit in one arm of the strain gauge bridge. Because the gauges were unavoidably disturbed when protective media were removed, the precise mode of failure could not be identified.

9.2 VEHICLE SPEED

As mentioned in Section 4, it was intended to ascertain the accurate calibration of the interruptor speed module upon return to the laboratory. However, due to an electrical malfunction caused by the test vehicle's electrical system, neither the fifth wheel speedometer nor interrupter module speed information was recorded. This did not affect the overall operation of the data recording system or the calculation of a strength rating method.

9.3 REPLACING MAGNETIC RECORDING TAPE

As there was limited space in the compartment where the instrumentation housing was located (in the sleeper cab) tapes could only be replaced with the test vehicle stationary. This did not prove to be a problem as the driver was most co-operative and timed his stops accordingly.

9.4 ON BOARD ANALYSER

As this was a one-off experiment, and the coupling force levels were unknown, the DASP provided instantaneous information on the acquired range of force levels. This enabled the experimenter to ensure that the measuring and recording instruments were utilised over their correct working range.

9.5 DATA ANALYSIS

Subsequent analysis of recorded analog data was performed in the laboratory in two stages. Firstly a typical scaled force amplitude distribution obtained by DASP is shown in Fig 19. Secondly spectral analysis is proceeding with an HP3582A Spectrum Analyser. A complete analysis of coupling force data and recommendations for strength ratings are given by Sweatman (1980).

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DISTRIBUTION TO INCLUDE: Directors, NAASRA Eng-Sec., NAASRA PEC Committee, RUSC, RTEL.

REFERENCES

SWEATMAN, P.F. (1980). Strength requirements for tow couplings in road trains. Australian Road Research Board, Internal report AIR 1083-1.

TABLE I

TABULATION OF APPLIED FORCE VERSUS TRANSDUCER OUTPUT

Applied Force (kN)	Output Ectron Amplifier (V)	Calculated from Line of best fit Equation (V)	Difference (V)
0	2.500	2.463	-0.015
10	2.615	2.585	-0.030
20	2.740	2.707	-0.033
30	2.857	2.829	-0.028
40	2.974	2.950	-0.074
50	3.092	3.072	-0.020
60	3.212	3.194	-0.018
70	3.332	3.315	-0.017
80	3.447	3.437	-0.010
90	3.566	3.559	-0.007
100	3.684	3.680	-0.004
110	3.802	2.802	0
120	3.924	3.924	0
130	4.043	4.046	+0.003
140	4.162	4.167	+0.005
150	4.282	4.289	+0.007
0	2.490	2.463	-0.027
-10	2.366	2.342	-0.024
-20	2.245	2.220	-0.025
-30	2.122	2.098	-0.024
-40	2.000	1.977	-0.023

TABLE I *cont.*

TABULATION OF APPLIED FORCE VERSUS TRANSDUCER OUTPUT

Applied Force (kN)	Output Ectron Amplifier (V)	Calculated from Line of best fit Equation (V)	Difference (V)
-50	1.874	1.855	-0.019
-60	1.754	1.733	-0.021
-70	1.630	1.612	-0.018
-80	1.504	1.490	-0.014
-90	1.384	1.358	-0.016
-100	1.257	1.246	-0.011
-110	1.136	1.125	-0.011
-120	1.014	1.003	-0.011
-130	0.890	0.881	-0.009
-140	0.767	0.760	-0.007
-150	0.646	0.630	-0.008

TABLE II

ECTRON 314A AMPLIFIER ENVIRONMENTAL SPECIFICATIONS

Environment:	
Temperature:	All specifications apply, -25° to + 93°C.
Vibration:	Output noise will not exceed 75 mV p-p for 35 g peak vibration 30 to 2000 Hz.
Shock:	Output noise will not exceed 100 mV for shock of 2500 g, 0.5 milliseconds each axis.
Humidity:	100 per cent RH.
Electromagnetic Interference:	All input, output and power leads are decoupled using EMI filters.
Mechanical:	
Size:	Less than (1 cu. in.) 16.5 cm^3
Weight:	42 g

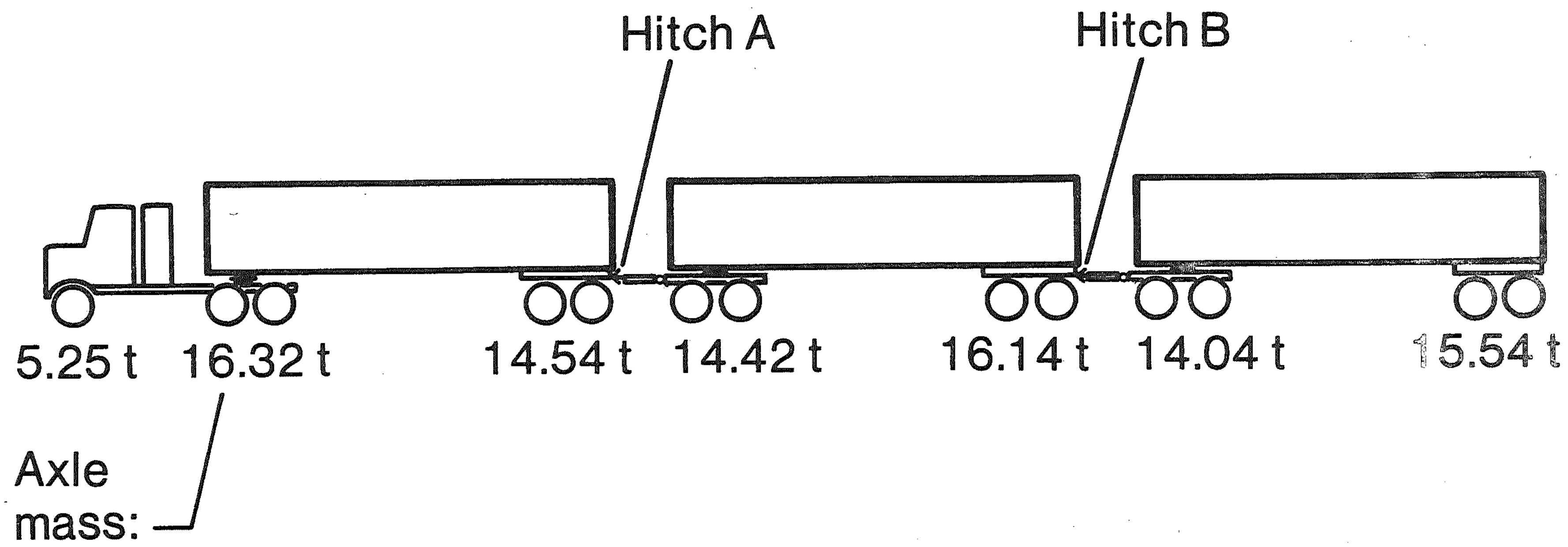

Fig 1 - Road train configuration and axle loads

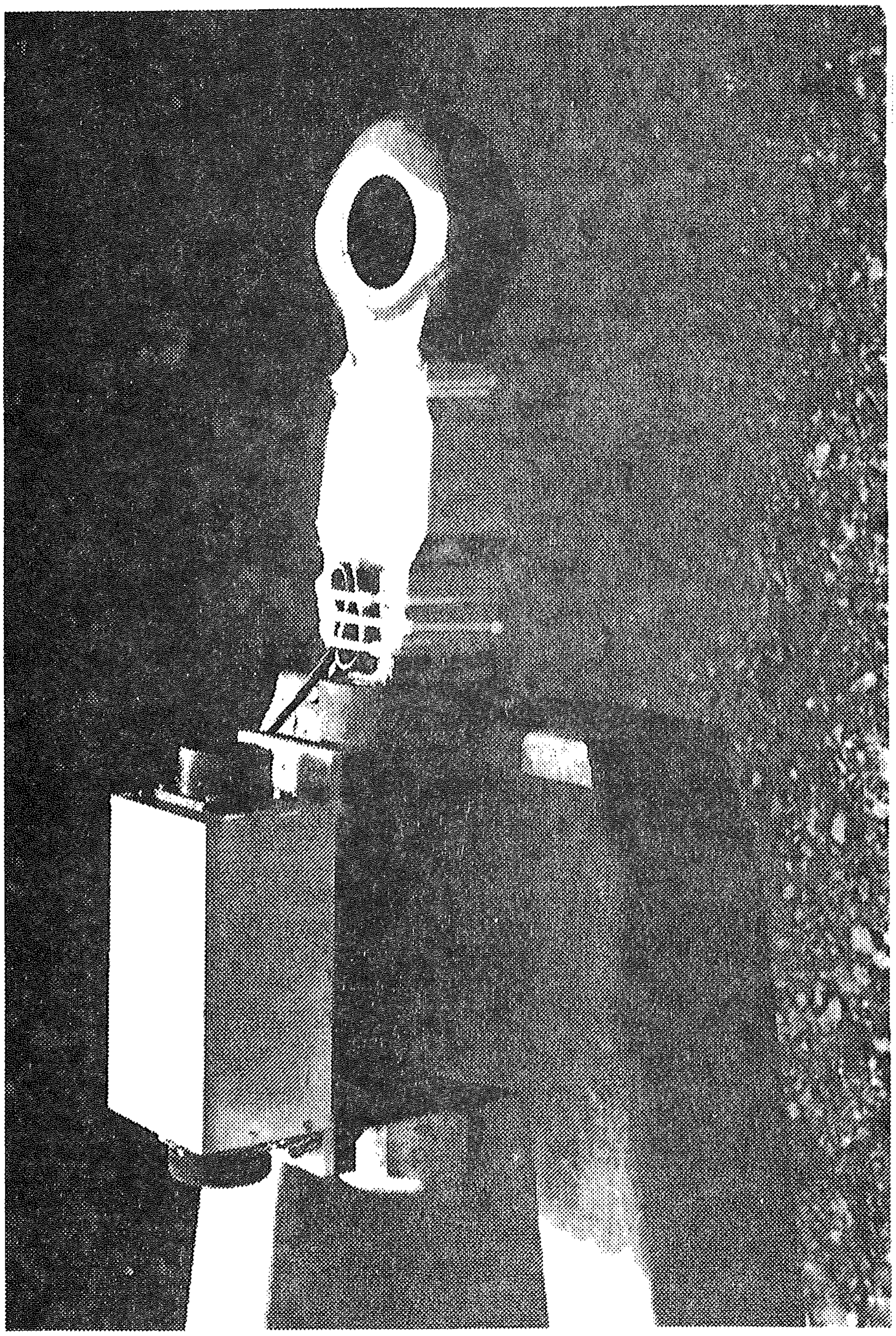

Fig 2 - Coupling eye transducer and instrumentation housing mounted on a towing frame

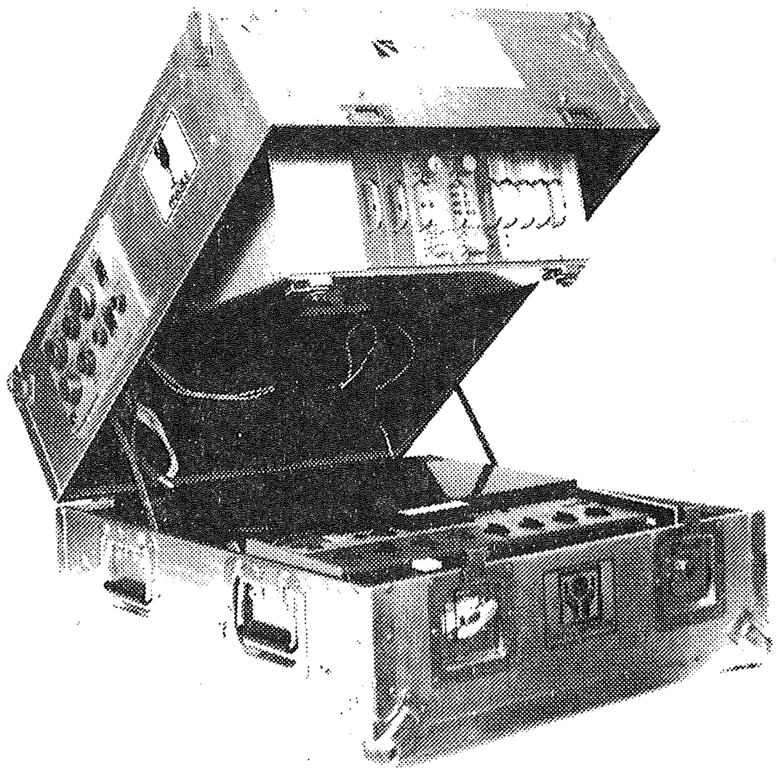

Fig 3 - Instrumentation FM magnetic tape recorder and electronic instrumentation, mounted in housing

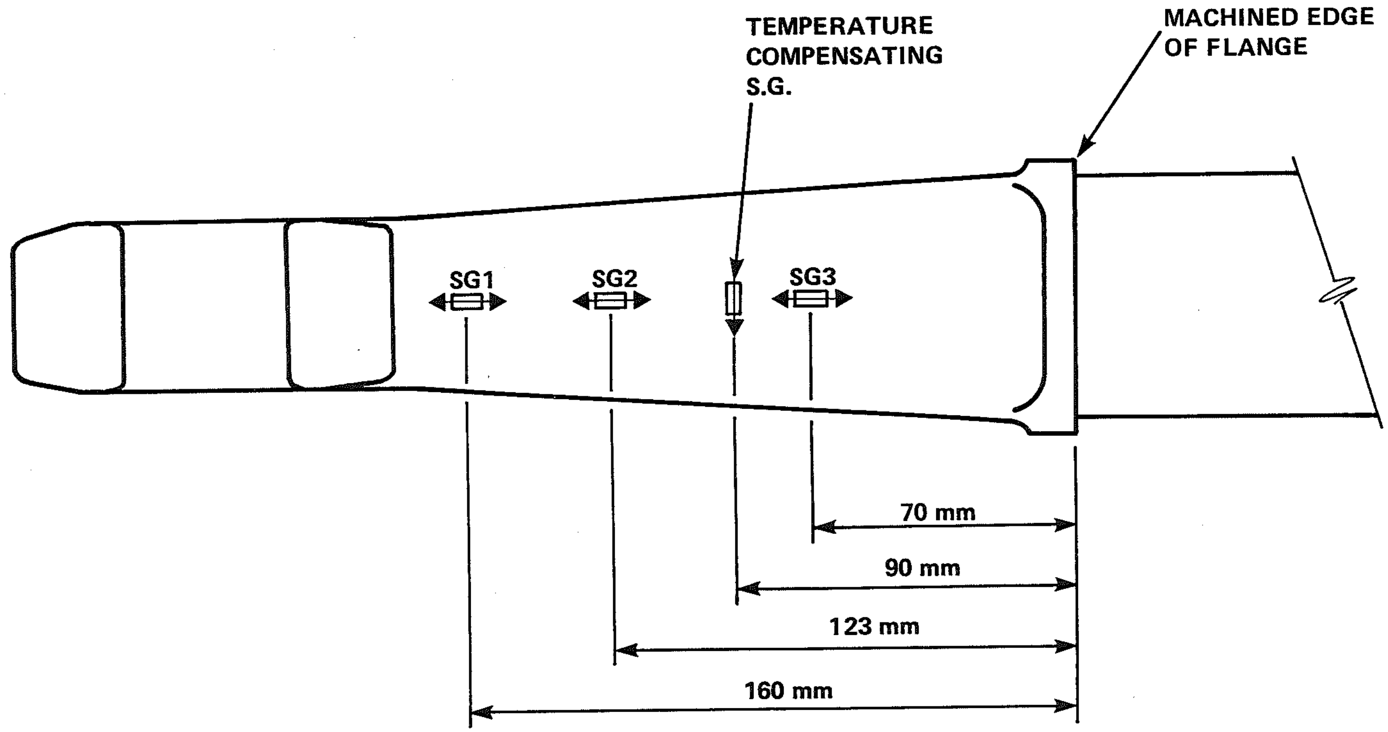

Fig 4 - Location of experimental strain gauges (SG) on a VBG-881
50 mm coupling eye

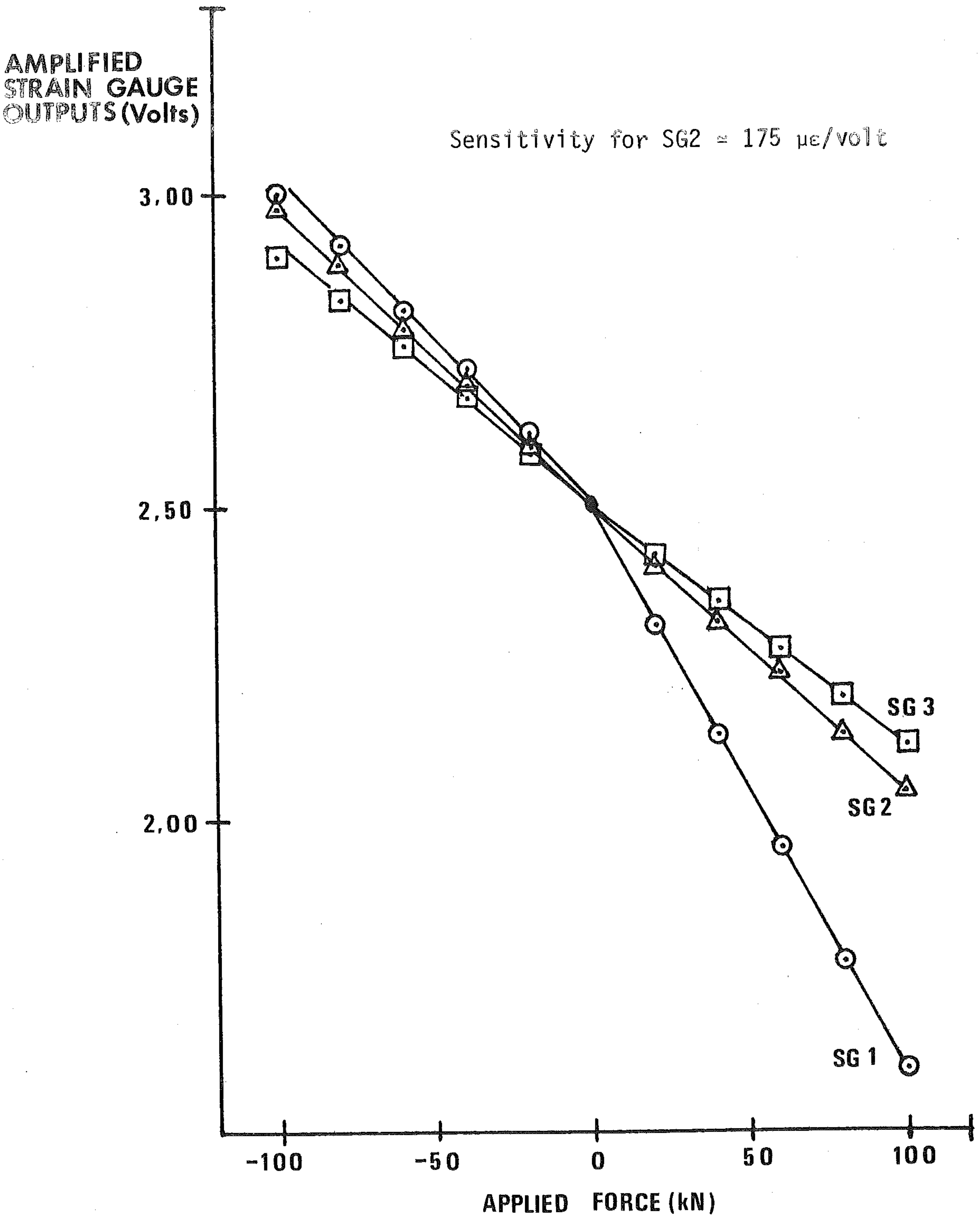

Fig 5 - Plot at applied force against amplified strain gauge output for three experimental strain gauge locations

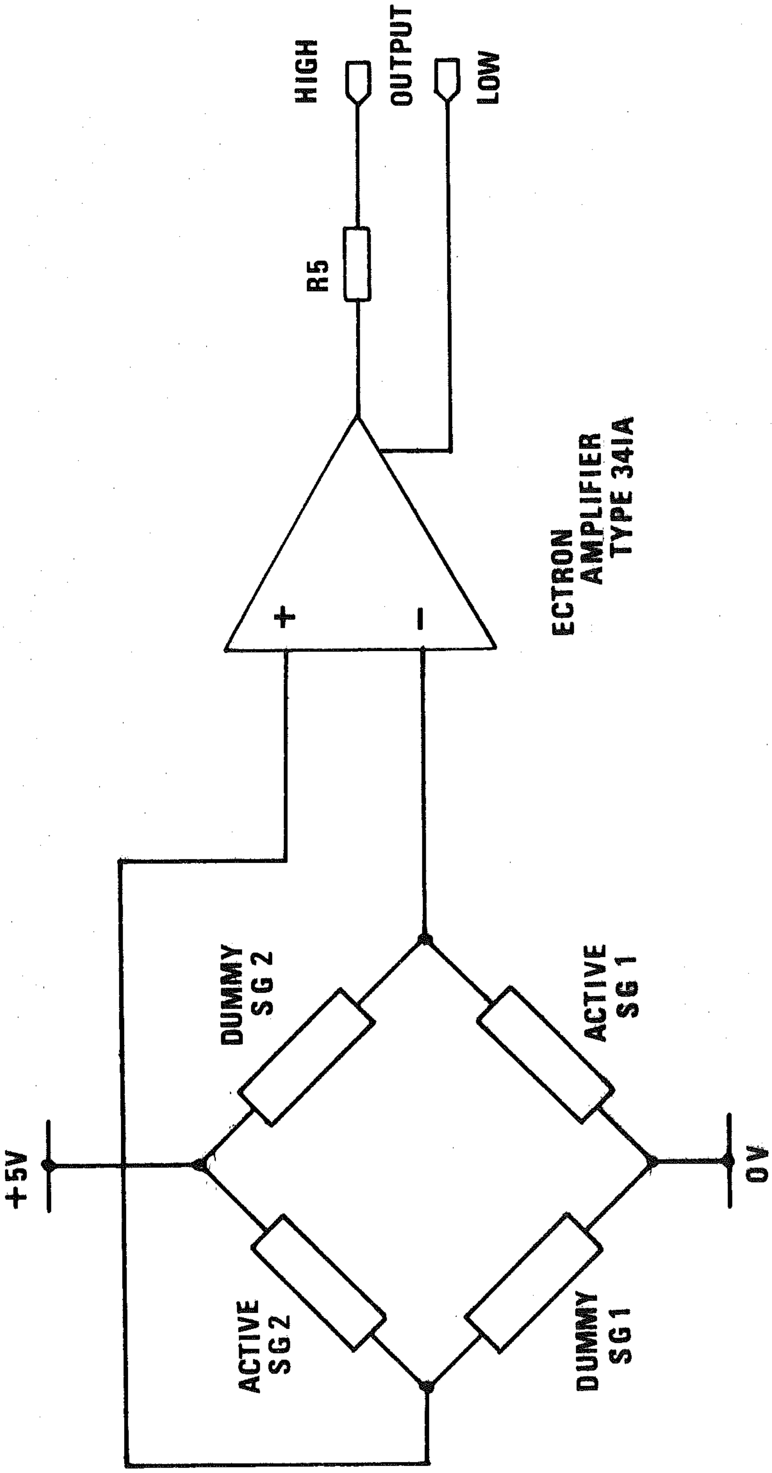

Fig 6 - Full strain gauge bridge configuration connected to instrumentation amplifier

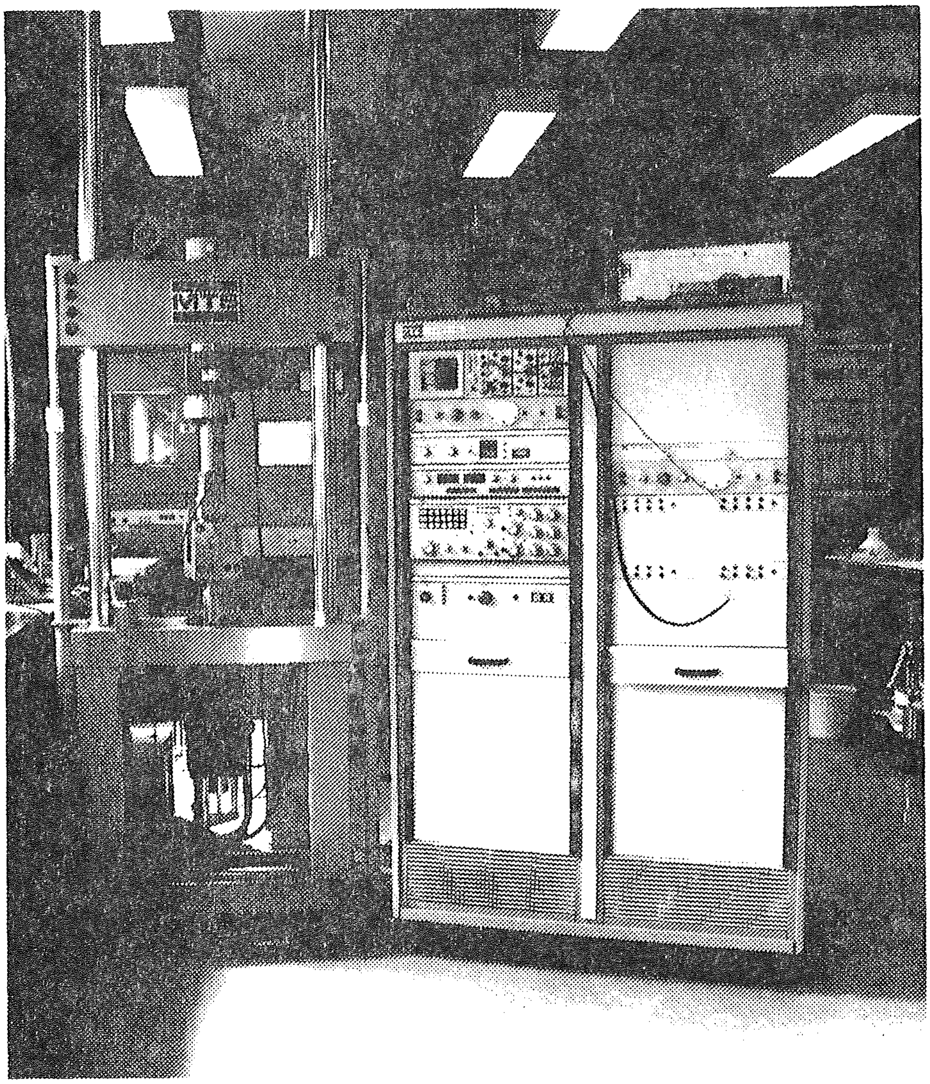

Fig 7 - Strain gauged tow coupling eye mounted in the material test system (MTS) facility

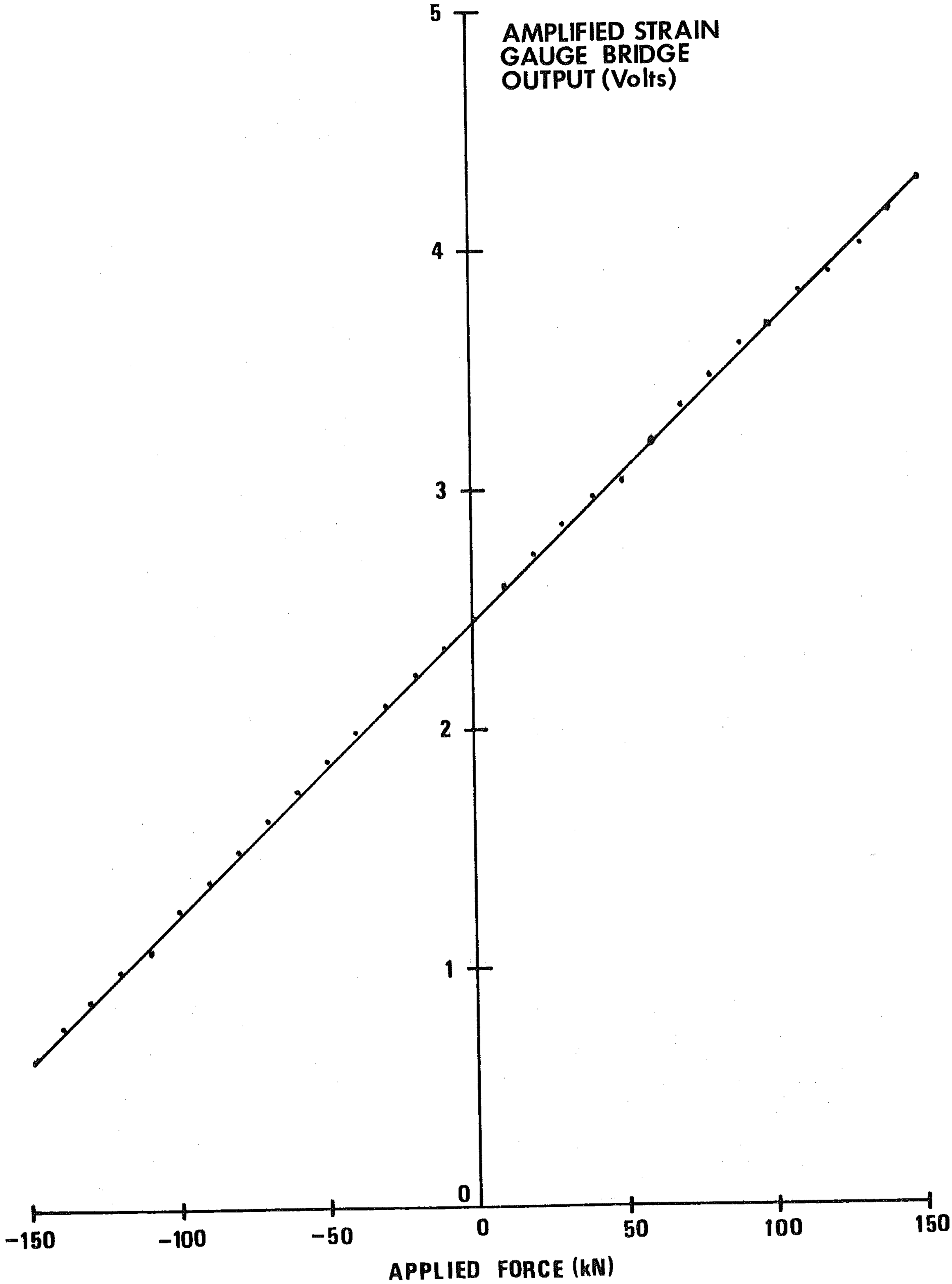

Fig 8 - Final calibration of hitch coupling eye force transducer

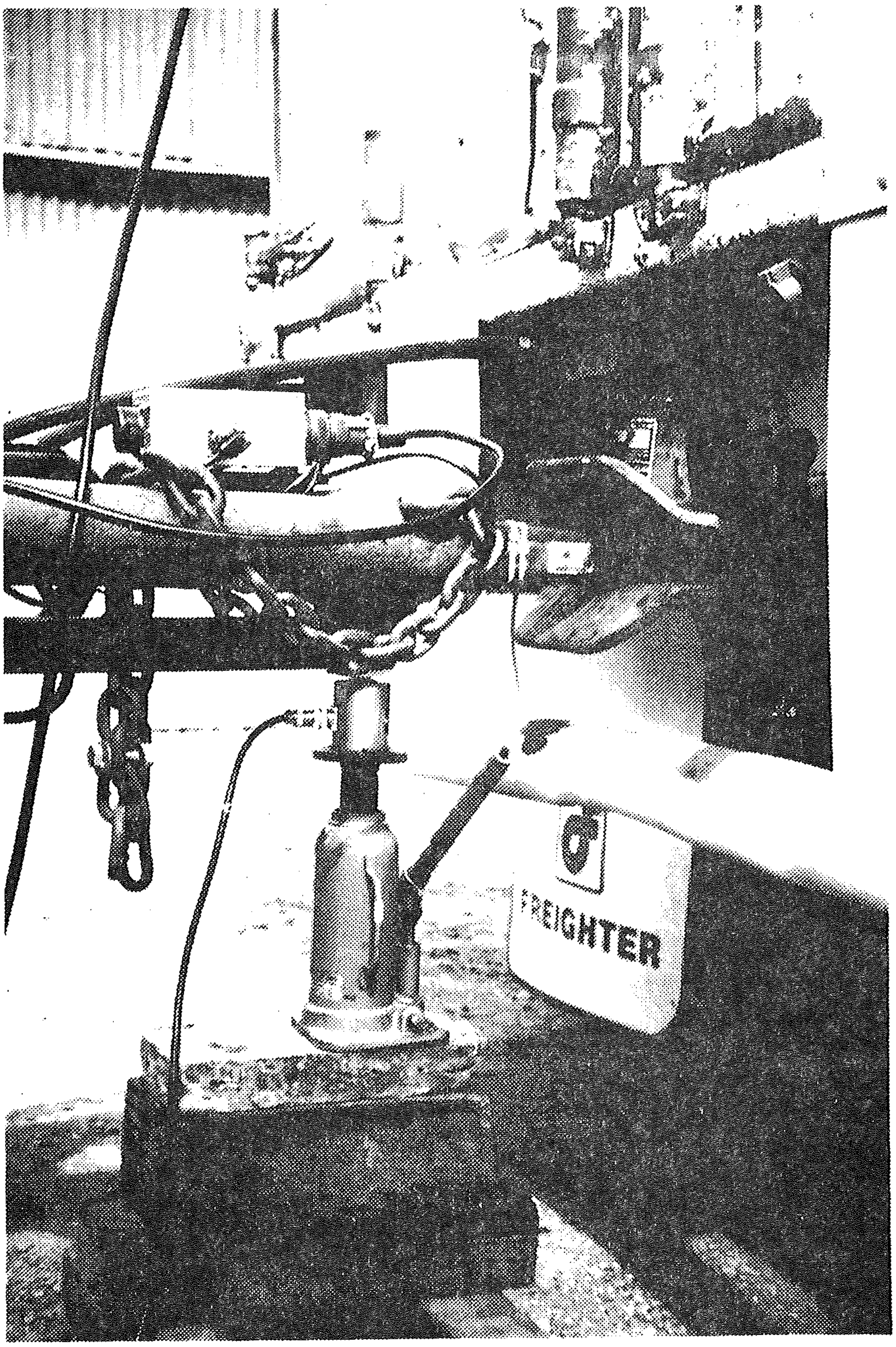

Fig 9 - The cross axis coupling sensitivity test. A jack was used to apply a force through a load, 330 mm from the coupling pin, along the centre line.

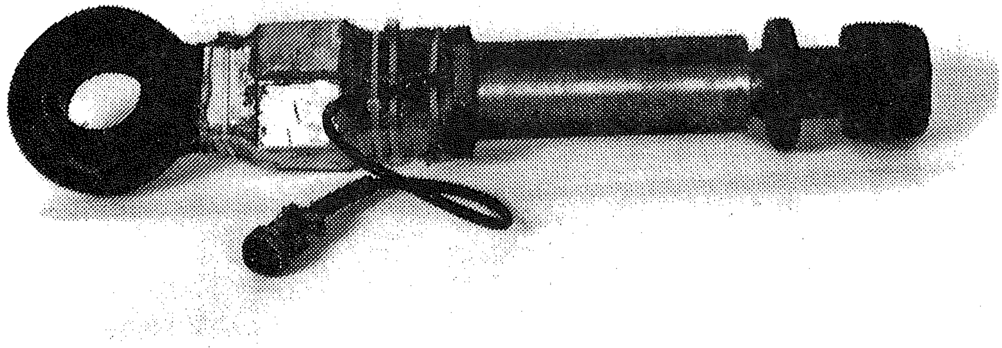

Fig 10 - Tow eye coupling transducer environmentally protected

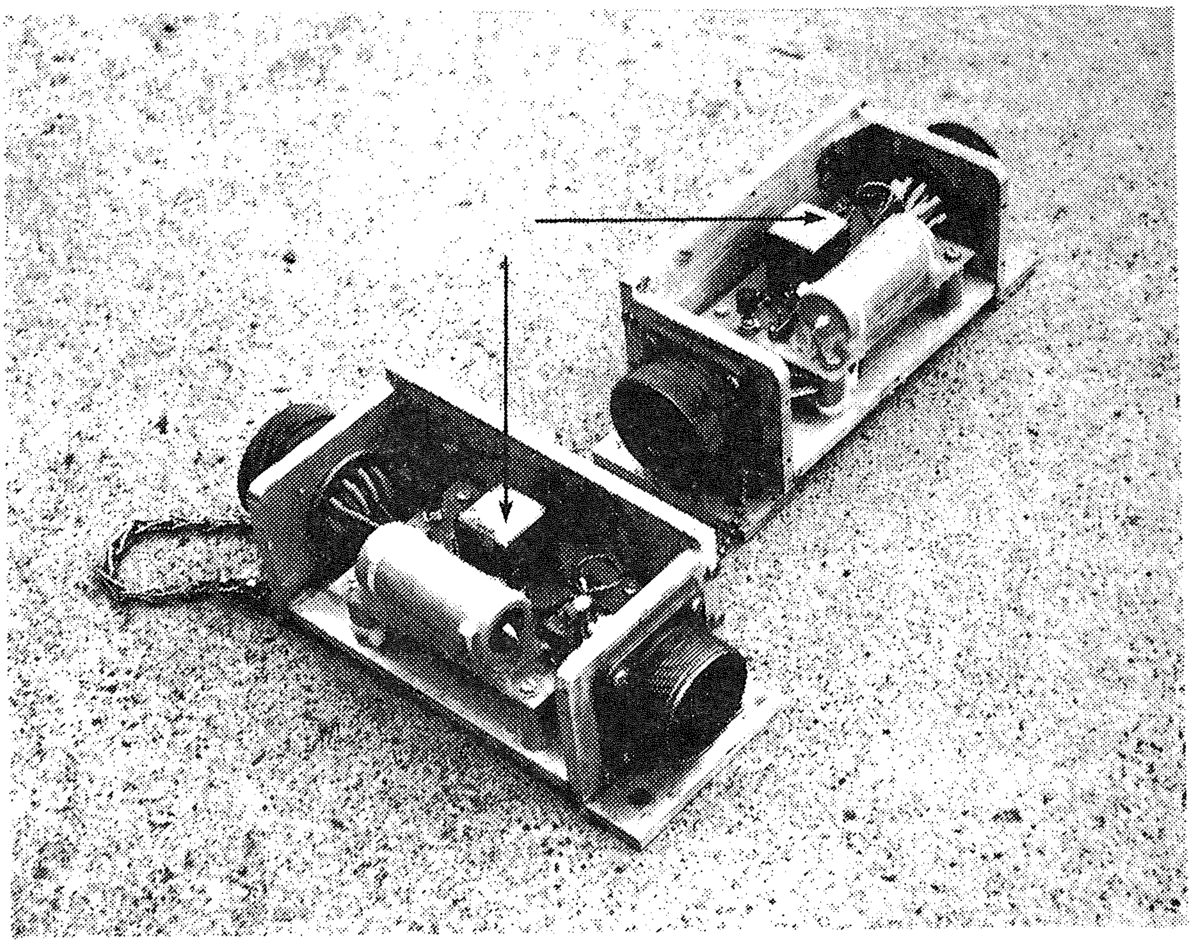

Fig 11 - Ectron Amplifiers mounted in environment proof housings shown with the covers removed

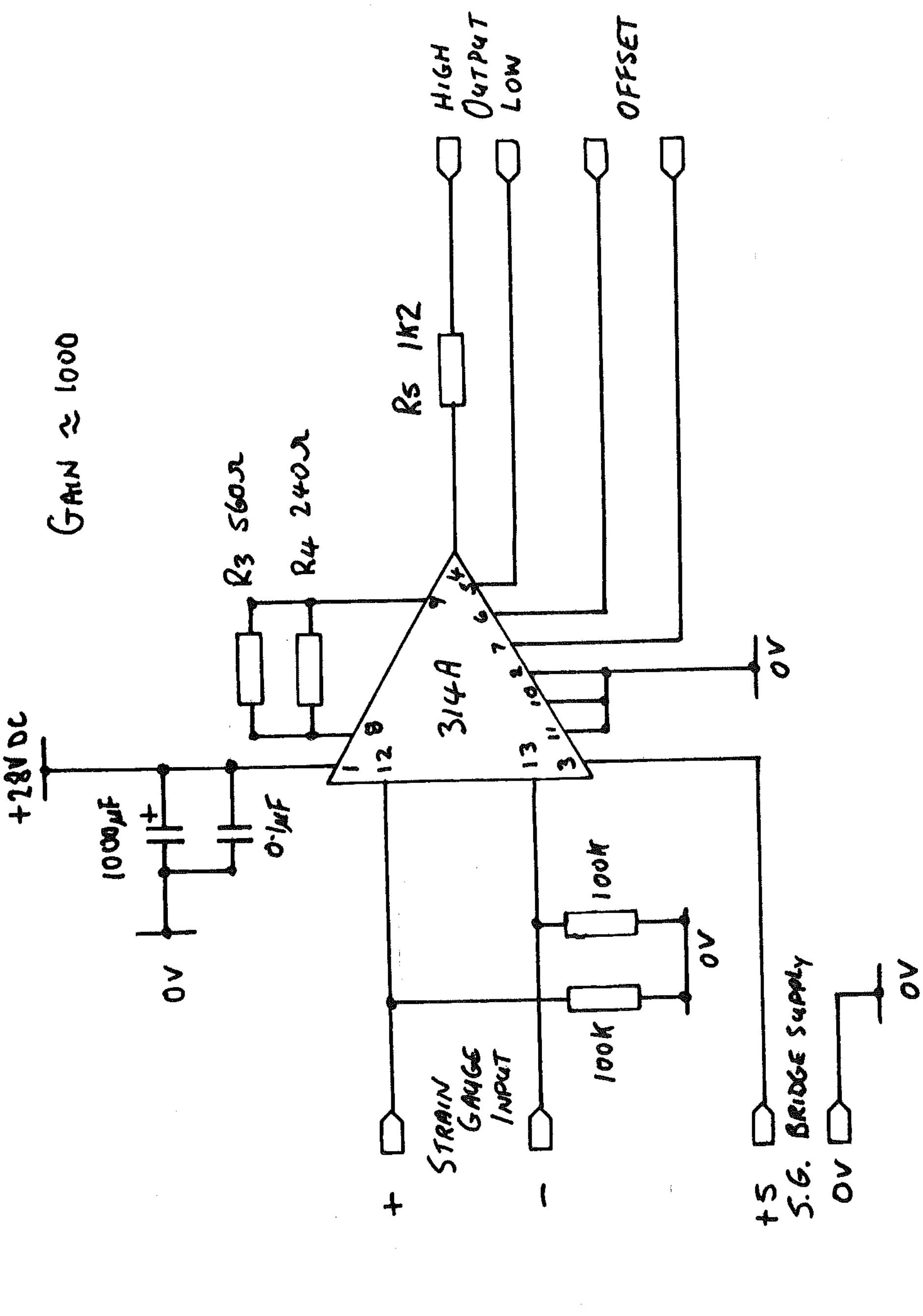

Fig 12 - Ectron amplifier circuit configuration

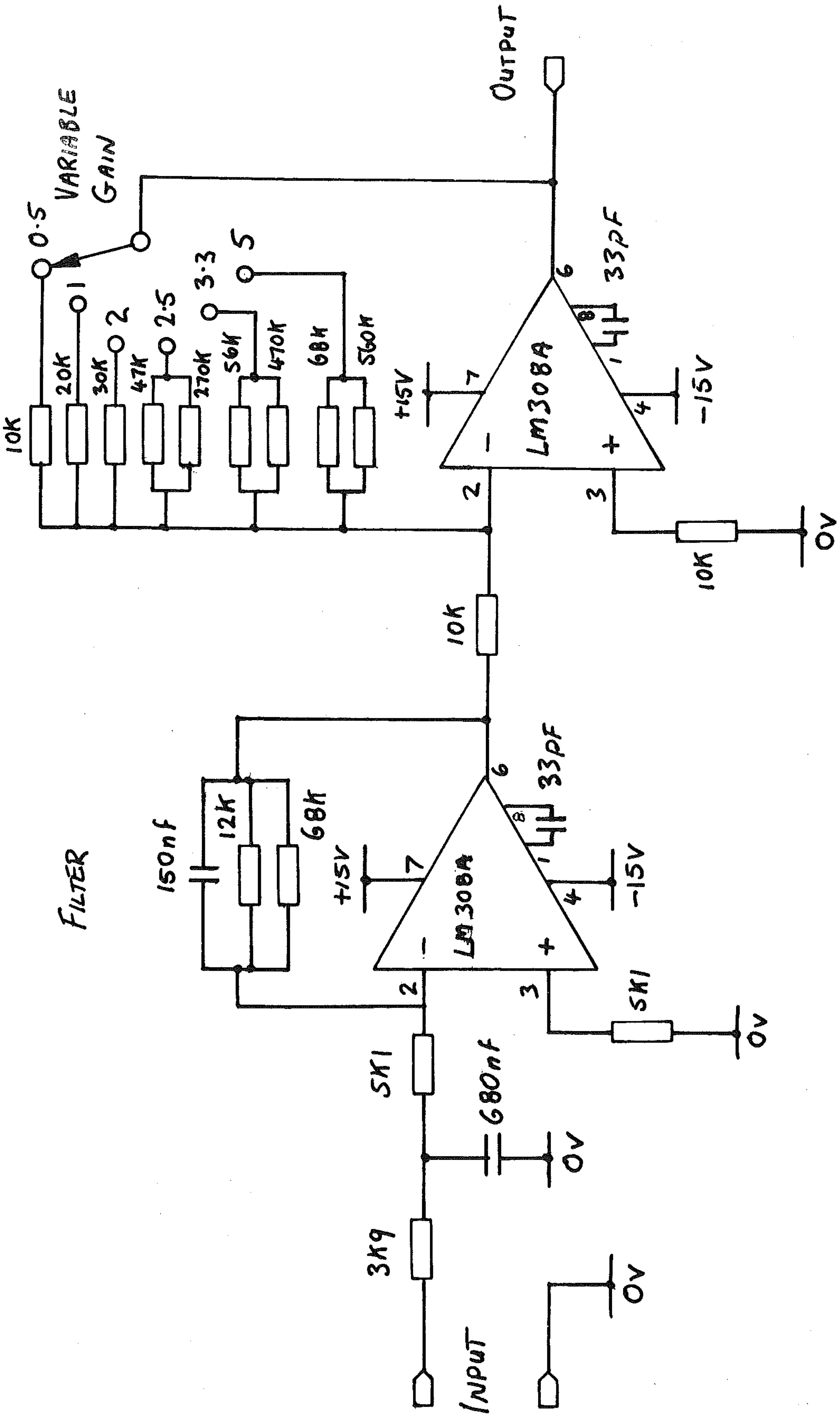

Fig 13 - Circuit diagram of active filter and variable gain circuitry

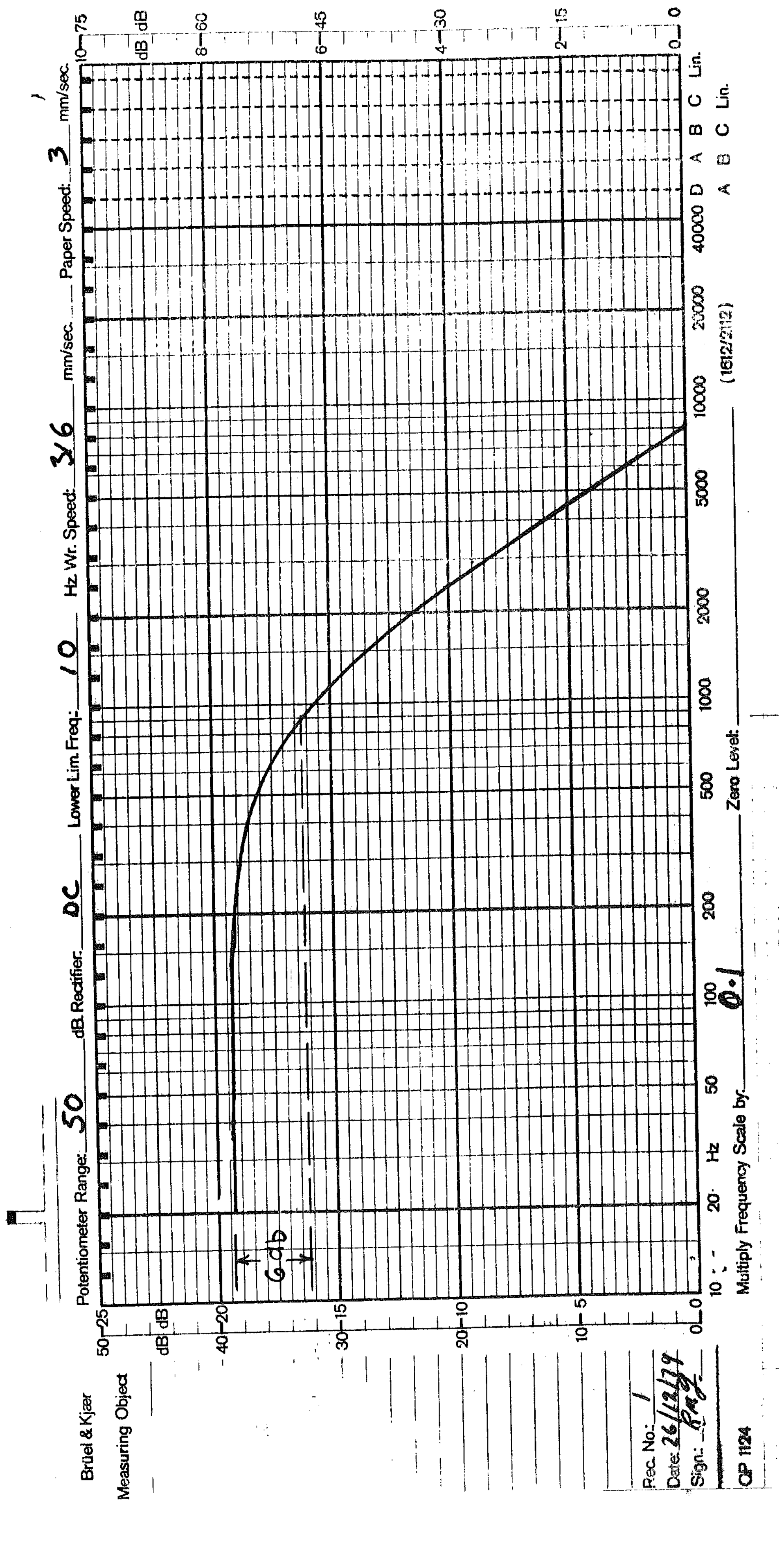

Fig 14 - Frequency versus amplitude plot for the two pole active filter

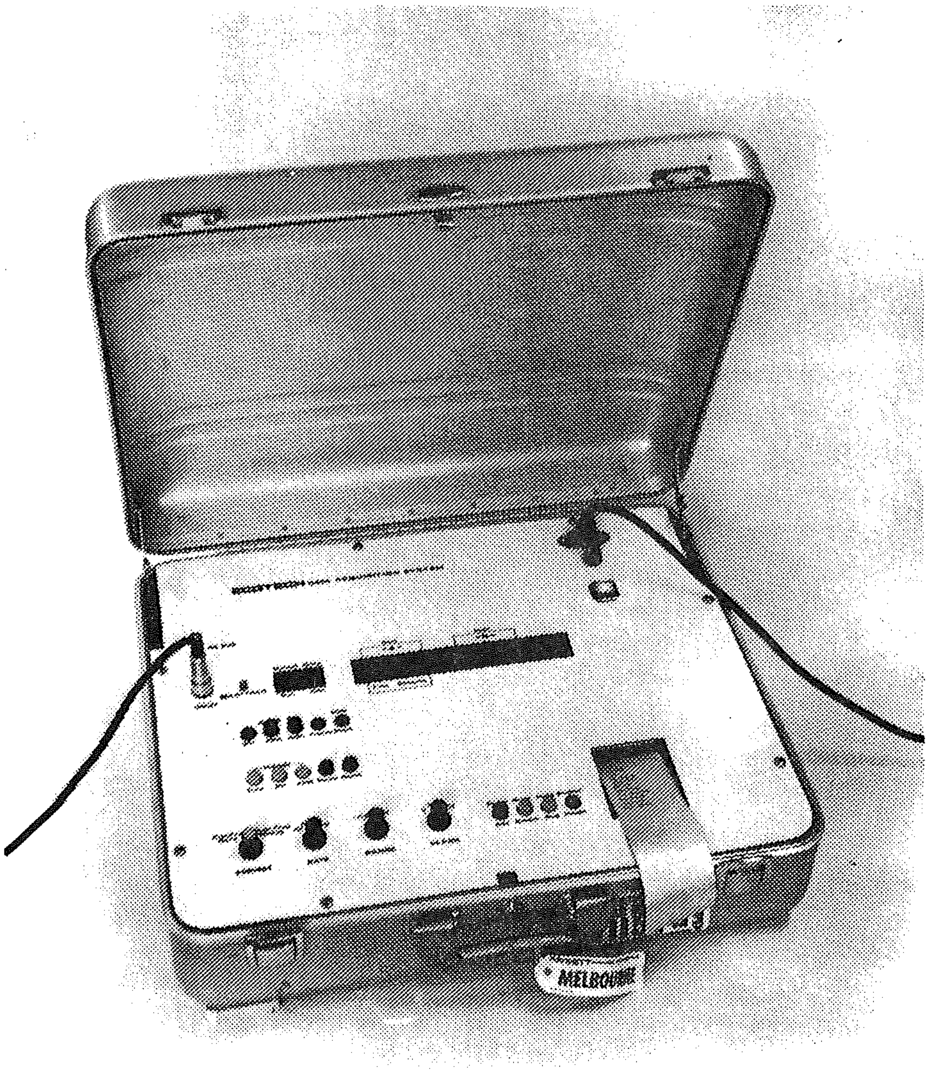

Fig 15 - The microprocessor based data analyser and statistical processor (DASP)

CHANA

012	0000001
018	0000001
019	0000001
020	0000001
021	0000001
022	0000001
023	0000001
024	0000003
025	0000005
026	0000007
027	0000012
028	0000018
029	0000027
030	0000039
031	0000073
032	0000082
033	0000127
034	0000160
035	0000160
036	0000293
037	0000310
038	0000473
039	0000573
040	0000840
041	0001132
042	0001645
043	0002289
044	0003680
045	0005515
046	0009329
047	0014115
048	0024589
049	0043963
050	0076472
051	0104631
052	0137180
053	0152085
054	0167582
055	0157615
056	0148399
057	0124030
058	0097640
059	0065303
060	0046736
061	0031127
062	0021116
063	0013065
064	0008734
065	0005960
066	0003885
067	0002395
068	0001719
069	0001040
070	0000684
071	0000433
072	0000282
073	0000201
074	0000171
075	0000101
076	0000104
077	0000057
078	0000033
079	0000048
080	0000033
081	0000018
082	0000020
083	0000012
084	0000015
085	0000008
086	0000005
087	0000004
088	0000002
089	0000003
090	0000001
091	0000003
093	0000002
094	0000001
096	0000003
106	0000001
110	0000001

FREQUENCY OF OCCURRENCE

CLASS INTERVAL NUMBER

Fig 16 - A typical probability density distribution (raw data) print-out from DASP. For Channel 'A' only.

```
CHANA
045 $
046 $
047 $$
048 $$$
049 $$$$$$
050 $$$$$$$$$$
051 $$$$$$$$$$$$$$
052 $$$$$$$$$$$$$$$$$$$
053 $$$$$$$$$$$$$$$$$$$$$
054 $$$$$$$$$$$$$$$$$$$$$$$
055 $$$$$$$$$$$$$$$$$$$$$
056 $$$$$$$$$$$$$$$$$$$$
057 $$$$$$$$$$$$$$$$$
058 $$$$$$$$$$$$$
059 $$$$$$$$$
060 $$$$$$
061 $$$$
062 $$$
063 $$
064 $
065 $
066 $
CHANA AV.0.331
STAND.DEV.A=0.071
```

CLASS INTERVAL NUMBER.
EACH $ SYMBOL REPRESENTS 0.5% OF TOTAL FREQUENCY OF OCCURRENCE

Fig 17 - A typical probability density distribution histogram print-out from DASP for raw data shown in Fig 16. Channel 'A' only.

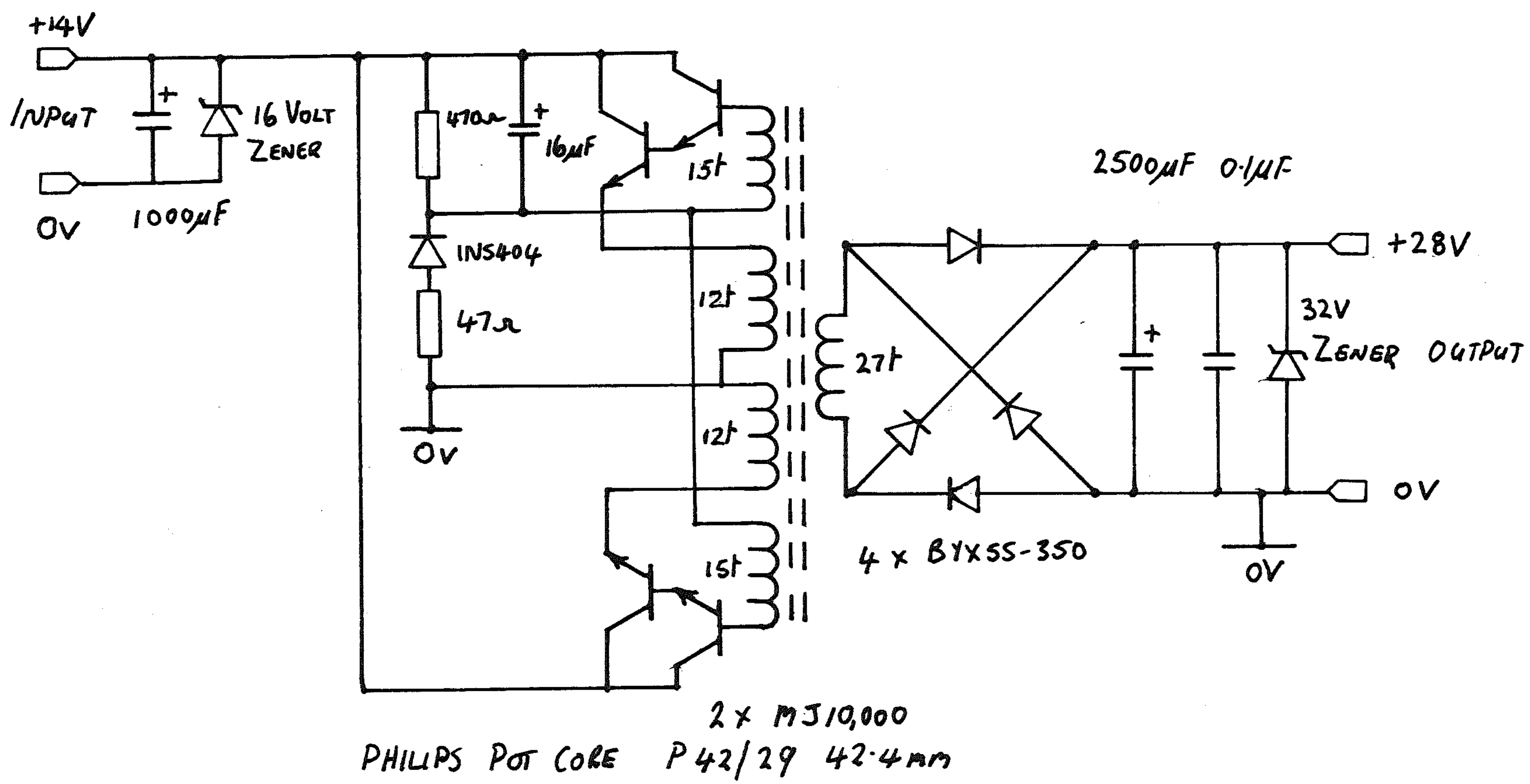

Fig 18 - Circuit diagram of 28 volt inverting power supply

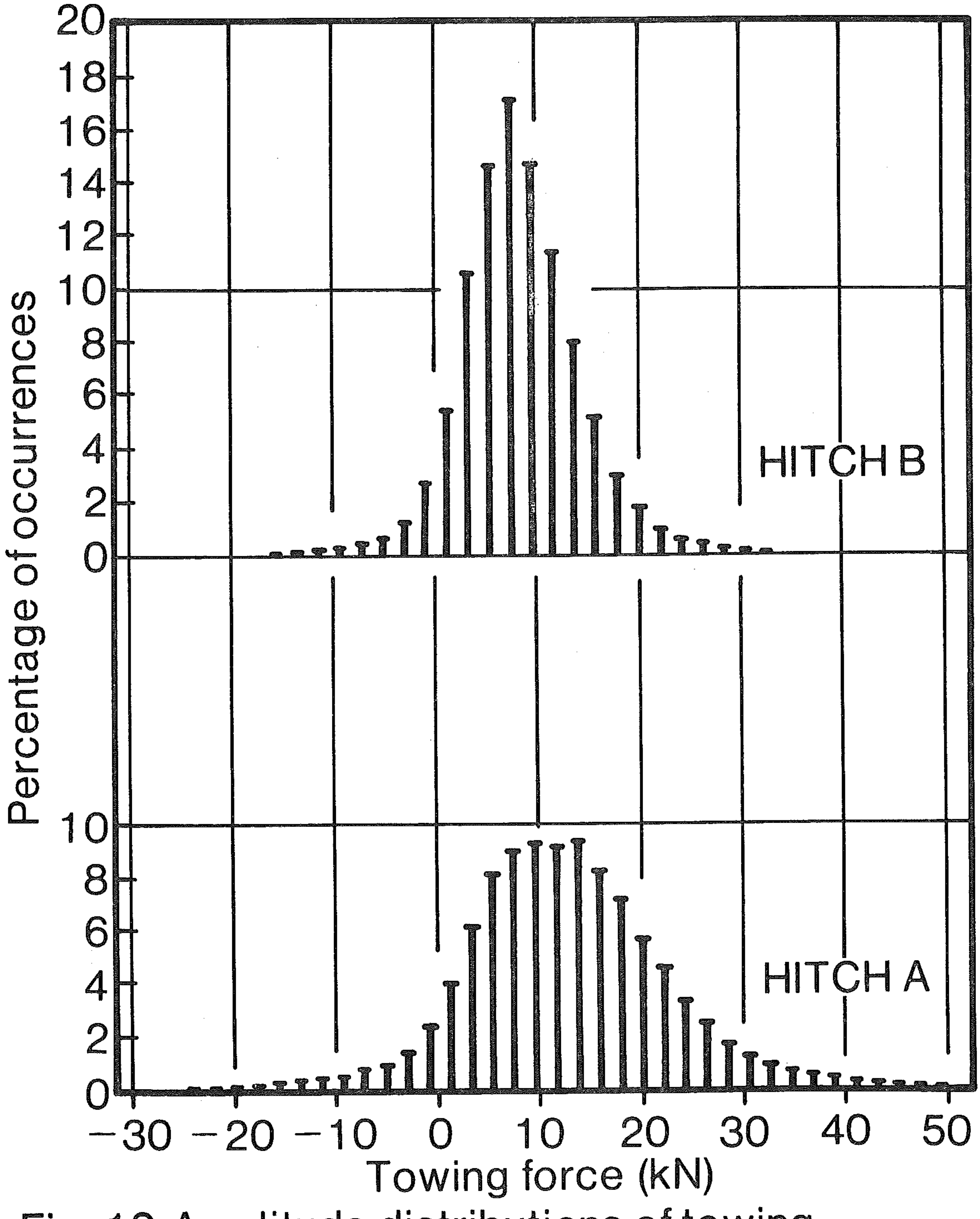

Fig. 19 Amplitude distributions of towing forces in a triple operating on an unsealed road (log 13)