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A Control and Measurement System for Aeroelastic Model Tests

by

W. D. T. Hicks

Structures Dept., R.A.E., Farnborough

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A CONTROL AND MEASUREMENT SYSTEM FOR AEROELASTIC MODEL TESTS

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SUMMARY

A semi-automatic data handling system has been constructed at the R.A.E. for use in wind tunnel and laboratory tests on aeroelastic models. The system can accept fifty inputs of static information and fifty oscillatory inputs; the latter can be analysed to yield the components of each input that are in-phase and in-quadrature with a sinusoidal reference signal.

The system can be programmed to handle, automatically, sequences of input data and, after analysis, to output the data in printed form and on punched paper tape. Graphical presentation of analysed oscillatory data is provided.

The equipment has been used in several wind tunnel test programmes resulting in an economical use of wind tunnel test time and skilled manpower.

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* Replaces R.A.E. Technical Report 68238 - A.R.C. 31034

CONTENTS

1 INTRODUCTION

In recent years, the development of aeroelastic modelling techniques, and, in particular, the need to extract an increasing quantity of data from a model test, have made it essential to improve methods of data handling. Whereas it was once acceptable for a wind tunnel test of a flutter model to yield only a critical flutter speed and frequency for each test configuration, it is now almost a routine procedure to investigate the subcritical response in a number of modes over a range of tunnel conditions. Thus the complexity and quantity of instrumentation have increased, and the amount of data obtained from a wind tunnel test is formidably large. At the same time, it is necessary to analyse test results rapidly, since a knowledge of model behaviour at one test condition will determine whether or not it is safe to proceed to a more critical condition. If the analysis is slow, then expensive tunnel occupation time is wasted, and if no analysis is made there is a risk of losing a costly model and perhaps of damaging the wind tunnel. For these reasons, the equipment described in this Report has been built at the R.A.E. for aeroelastic model testing.

Use of the equipment in a variety of wind tunnel and laboratory tests has shown that it fulfils its design purpose, and that the facilities it provides enable nearly all the test procedures associated with aeroelastic models to be followed with an economy of time and effort that could not have been achieved without the equipment.

2 GENERAL DESCRIPTION

The procedures involved in any aeroelastic model test require similar instrumentation and similar analysis. In dynamic tests of models (whether they are subcritical response tests in wind tunnels, or resonance tests in the laboratory) it is necessary to provide:-

(i) a sinusoidal force input

(ii) a means of measuring and varying the frequency of the input

(iii) a selector to enable one of a number of response signals to be monitored and analysed

(iv) a resolving system to separate the components of a response signal relative to the force input, and

(v) a data recording unit which will handle all the relevant test information.

In static tests of aeroelastic models, (such as influence coefficient measurements), it is necessary to provide only the facilities listed under (iii) and (v) above.

Strictly, a data handling system for aeroelastic model tests could be separate from the control system used in the tests, but since neither system is, in practice, likely to be used without the other, it was decided to incorporate both into one comprehensive unit. The components of the system were chosen to satisfy the provisions of (i) to (v) above, and to provide additional facilities which will be described.

A block diagram of the system is shown in Fig.1 and the use of each component in relation to the above provisions is as follows.

The usual forcing system in aeroelastic model tests is an electromagnetic exciter driven by a power amplifier which is controlled by an oscillator. The oscillator signal is also the reference signal for all phase measurements required in the experiment and thus the oscillator is the basic sub-unit of the system. The power amplifier and exciter are not included in the system since these will vary from test to test. Provision is also made for other forms of excitation - such as inertia or mechanical excitation - by including a unit (the mechanical reference generator) to generate a reference signal from a transducer on the exciter. The reference signal selected for a particular test is passed to the resolved components indicator, and also to a frequency counter.

Fifty channels of oscillatory input (usually signals from response transducers on the model) are taken to a selector which enables them to be fed sequentially to the resolved components indicator after amplification. The selection can be either manual or automatic. Provision is made for monitoring selected signals on an oscilloscope, and also for feeding an external input to the resolved components indicator.

After resolution of an oscillatory input signal into its components in-phase and in-quadrature with the reference signal, the component outputs of the resolved components indicator are taken through a switch to a digital voltmeter and thence to the data assembly unit and output system. The components of an input signal can also be fed to an X-Y plotter if vector plots are required.

Fifty channels of steady voltage input may also be selected either manually or automatically and fed to the output system through the digital voltmeter.

The data assembly unit is provided with pre-set data such as wind tunnel operating conditions, run numbers, etc., so that the output, which can be typewriter print-out or punched tape (or both), contains all the information that needs to be retained. An overall control unit enables the operator to start, stop, or reset a test sequence at any time.

Details of the system are given in the following sections.

3 SYSTEM DETAILS

All the main components of the system are commercial items of equipment, and the manufacturers and type numbers are listed in the Appendix. With the exception of the resolved components indicator, all the items are incorporated in the system in their commercial form.

In describing the system in detail, it is convenient to start with the output stage, since an initial knowledge of the output format clarifies the functions of the intermediate stages between input and output.

The output of the system is on five-hole punched paper tape using the code shown in Fig.2. A parallel typed output in the pre-determined format shown in Fig.3 is also provided.

3.1 Format control

A central Control Unit switches the outputs from the system components in a pre-programmed sequence to the output printer and tape punch. The Control Unit also supplies format and spacing symbols which appear on the tape but which are not immediately observable as symbols on the print-out. The Control Unit sequence is initiated by means of a press-button marked "Record". The output sequence begins with twenty-one Figure Shifts (Fig.2). The symbol for Figure Shift appears as a blank on the punched tape but produces no symbol on the typed print-out (Fig.3). Each run, therefore, is separated by twenty-one blanks on the tape, making it easy for the operator to identify each run and, if necessary, to cut the tape into sections for editing.

These Figure Shifts are followed by Carriage Return, Line Feed, Letter Shift symbols and the word 'RUN' is printed out and punched on the tape. Further Letter Shift, Carriage Return and Line Feed symbols are inserted on the tape as needed to provide the format of the print-out.

3.2 Pre-set data

The word 'RUN' is followed by a Serial Number from a Serial Number Counter which moves on automatically at the end of each run. The counter can be manually re-set to zero by press-buttons adjacent to it if required for a series of runs.

Twelve items of manually pre-set information are then printed out. These appear as four-figure numbers which are set by the operator before a run by means of edge-operated thumbwheel switches. They are used for the inclusion of any factors which may identify or have an effect on the results of a run. Examples would be the date, wind-tunnel conditions, model description, ambient conditions etc.

3.3 Static measurements

Following the pre-set data a block of fifty four-figure numbers appears, each preceded by a negative signal or suppressed positive and a single-figure multiplier number. The multiplier number is not a direct multiplier but a symbol for the manually controlled equipment sensitivity range. The number will vary from 1 through to 6. The equivalent factors are:-

$$1 = 10^{-5}$$
$$2 = 10^{-4}$$
$$3 = 10^{-3}$$
$$4 = 10^{-2}$$
$$5 = 10^{-1}$$
$$6 = 1 .$$

These factors convert the four-figure number to a measured reading in volts.

The four-figure numbers are the print-out from a digital voltmeter. The input to the digital voltmeter is from a bank of fifty input points selected in turn by the Control Unit. These input points are for connection to analogue transducers providing a static or slowly-changing output voltage representing, for example, changes in wind-tunnel pressure, temperature etc. or for recording response of the structure to static loading. The form taken by the transducer is unimportant but the output voltage must be dc or changing very slowly. The sampling and reading period of the digital voltmeter is twenty milliseconds.

The block of static readings is followed by an asterisk. This symbol marks the end of the static measurement run and is included because the number of items of static information can be manually pre-set before a run to be any number up to the full fifty. The asterisk can, therefore, serve as a marker in a computer control program.

3.4 Frequency record

Below the asterisk in the print-out appears an eight-figure number. This is a measurement of the frequency of the oscillator driving the excitation equipment and is thus the basic frequency reference. The eight-figure number is taken from the output of a digital frequency meter. It may be a direct reading of frequency or a count of the period of one cycle or more. The significance of the number depends on the manual settings of controls on the frequency meter and the settings are not indicated in the print-out. Interpretation depends therefore on a knowledge of the approximate frequency in use. In a series of tests, selection of these manual settings is dictated by the frequency range in use and the accuracy required. Frequency is changed in small steps over a narrow range and the settings, once decided, would not require re-adjustment.

3.5 Oscillatory measurements

The frequency count is followed in the format by a block of a hundred four-figure numbers each of which is preceded by a negative or a suppressed positive sign and a three-figure number. In this block each measurement consists of two parts - the in-phase and quadrature components of transducer response signals from the oscillating structure under test, referred to the oscillator drive signal. The hundred numbers are arranged in rows of four so that, reading across the first row, (Fig.3) the first two numbers with their preceding groups of three multipliers are the in-phase and quadrature components respectively of the oscillatory output of the first transducer, and the remaining pair in the row the similar components of the output of the second transducer. This arrangement continues in order through the block for the full fifty transducer signals.

The three-figure multiplier before each in-phase or quadrature measurement consists of three code numbers which indicate the manually set factors from three instruments which are in the measurement line between the transducer and the digital print-out. These are, in the order in which their respective code numbers appear, an amplifier with switched gain positions, the resolved components indicating instrument with a switched attenuator at its input, and the range switch of the digital voltmeter.

The factors indicated by the code numbers are as follows:-

The first integer of the three is the code for amplifier gain position. This gain position multiplies the original signal a definite number of times according to the code setting. The final printed-out measurement must, therefore, be divided by the amplifier gain setting to obtain the original transducer signal. The manually pre-set amplifier gain control is marked on the amplifier as a gain setting and it is sometimes useful to know the gain position used in setting up. Both the gain and print-out conversion factors are listed below.

Gain of	10	=	code 1	=	factor 0.1
Gain of	20	=	code 2	=	factor 0.05
Gain of	50	=	code 3	=	factor 0.02
Gain of	100	=	code 4	=	factor 0.01
Gain of	200	=	code 5	=	factor 0.005
Gain of	500	=	code 6	=	factor 0.002
Gain of	1000	=	code 7	=	factor 0.001
Gain of	1	=	code 8	=	factor 1.0.

The code 8 position (factor = 1) is operated by a separate switch marked "Amplifier Out", which re-arranges the input circuit so as to by-pass the amplifier and, at the same time, to reverse the sense of the input signal from the transducer. (This avoids confusion of sign as the amplifier is sign-reversing.)

The second integer is the code for the Resolved Components Indicator input attenuator. The output of this instrument is always 1.5 volts for full-scale deflection as observed on its in-built meters and this is applied to the digital voltmeter. It is necessary, therefore, to apply a factor (which is dependent on the manually pre-set attenuator) to the digital voltmeter reading to obtain an accurate voltage measurement. These factors are listed below.

Attenuator switch	50 mV	=	code 1	=	factor	0.033
	150 mV	=	code 2	=	factor	0.1
	500 mV	=	code 3	=	factor	0.33
	1.5 V	=	code 4	=	factor	1.0
	5 V	=	code 5	=	factor	3.33
	15 V	=	code 6	=	factor	10.0
	50 V	=	code 7	=	factor	33.3
	150 V	=	code 8	=	factor	100.0
	Prime	=	code 9	=	factor	-

"Prime" is a switch position which disconnects the input signal and the appearance of code 9 on the print-out would mean that the switch had been left in the wrong position for taking measurement.

The third code integer is linked with the digital voltmeter range settings. The code number and factors are the same as those given for Static Information above.

The four-figure number which follows the block of three factors is the output of the digital voltmeter but with the decimal point, which appears on the voltmeter display panel, omitted. The decimal point is however, re-instated correctly when the factors given above are used and the number is regarded as whole.

The number of measurements of in-phase and quadrature components of incoming oscillatory signals can be limited to any number below fifty by adjustment of a pair of control switches. The final oscillatory measurement is followed on the print-out by "Carriage Return" and "Line Feed" symbols on the punched tape. The system then stops.

3.6 Additional symbols and controls

If required, "End of Tape" symbols consisting of an arrow (→), CR and LF, followed by seven "Erase" (*) characters can be inserted after the final measurement of a series by operating a push-button. This will also be inserted automatically if the button is pressed and locked before the start of a run.

Normally the settings of the various instruments would be made before a run is started and the factor code numbers would be the same throughout the run. Should it be necessary to change the settings an "Infinite" button can be operated which holds the action while adjustments are made. The new factor code numbers will then, of course appear for the remainder of the run. No other indication that this control has been used appears in the print-out.

An additional symbol which appears in the print-out Fig.3 is the "not-equals" sign ($\neq$). This indicates that a press-button switch marked "Reset" has been used during the course of an automatic run. Use of this switch returns the automatic system to the stand-by condition at the beginning of the automatic run. The appearance of the symbol would indicate that measurements made during the run were incorrect because of some error in instrument settings etc., and it could be used to instruct a computer to disregard readings back to the Run serial number.

3.7 Arrangement of components

Fig.1 is a block diagram of the layout and interconnections of the major instrument and recording components.

The Control Unit shown at the top of the diagram is basically a controlled digital clock providing output pulses of 2 Hz and 10 Hz. The 2 Hz signal trips the digital voltmeter (re-sets it to zero and starts the digital voltage measurement). The digital voltmeter has its own internal trip signal which must be switched off by turning the appropriate voltmeter panel switch to "Manual". The 2 Hz trip signal is inhibited, so that the voltmeter reading is held while it is read, serialized, and printed out.

The 2 Hz signal is also the time base for three "Delay" controls. These can be seen in the bottom right hand corner of the Control Panel (Fig.4). Each "Delay" control comprises two thumb-wheel switches which enable the operator to set the length of the delay in units of 1 second between recording each reading from the external static or oscillatory transducers. Normally the delay between reading each static signal would be kept as small as possible to make a rapid run through the selected number of transducers. The delay between reading oscillatory signals has to be set by the operator after observation of the response of the Resolved Components Indicator. At the lower frequencies this may take some few seconds to settle down to the final readings. This instrument is shown in the lower right-hand corner of Fig.5. The two large meters provide an analogue reading of the in-phase and quadrature components of the incoming signal and can be used to check the settling time. Whereas the voltages representing the oscillatory components are provided in parallel at the instrument they are digitized and printed sequentially. Delay times can be adjusted between reading each transducer and between reading the reference components. The delay switch marked "Phase" should be set according to the observed settling time of the meters, and it controls the pause between reading each transducer. The switch marked "Quadrature" adjusts the delay between reading the components and should normally be set to give the shortest possible pause between taking the two component readings.

The 10 Hz pulses from the Control Unit are the time base for the automatic sequencing, inhibiting, serialising and printing control networks. This frequency is dictated by the teleprinter speed.

A synchronising pulse is brought out from the Control Unit to a suitable plug point for connection to possible external switching equipment. This was included specifically for operating the control system for an external rotary switch which had been separately designed for switching proximity capacity gauges. It could, however, obviously be useful for operating other switching systems or external controlling networks for which a need might arise.

The Control Unit, through various inter-connected sub-assemblies fixes the final form of the print-out and inserts additional characters as required. The order in which the information is printed is shown by the vertical arrangement of blocks from top to bottom on the left of Fig.1. Adjacent to the Static Channel Selector block are two attached blocks marked Manual and Auto. Similarly, after the Oscillatory Channel Selector, four attached blocks are shown, three of which are marked Manual. The block marked Auto represents the automatic switching system in each case. Each adjacent Manual block represents a bank of press button switches which appear below the oscilloscopes in Fig.6. The four blocks of Manual switches are arranged in a square pattern on the Manual Switch Panel. The two on the left are linked with the Auto system in that, if any Static or Oscillatory channel is manually selected during the appropriate automatic scan by pressing a button on the "Tens" row and a button on the "Units" row, the automatic scan will stop when it has completed printing (or, immediately if in a Delay period), and will be held until the manual selection is cleared. The right hand pair of Manual switches are used only to connect any incoming oscillatory signal directly to the oscilloscopes shown in Fig.6 and do not affect the automatic system. It should be noted here that manual override of the automatic scan of static channels can only be effected when the total control scan has reached the static scan section and, in the same way, of oscillatory channels while the oscillatory scan section is in operation. The point reached in the automatic scan is indicated by a set of "Progress" lights in the centre of the panel shown in Fig.4.

Referring again to Fig.1, it can be seen that the Serial Number Unit and Pre-set Data Switches are directly connected to the Data Assembly Unit. The Serial Number Unit can be manually set to read zero before a series of runs and will be automatically stepped on one digit when each run has been completed.

The Static Channel Selector is connected to a switch with four marked positions. As previously described, when a static or oscillatory channel is manually selected the automatic sequence is held, but for the chosen channel output to be measured on the Digital Voltmeter this switch has to be appropriately set. Returning it to the "Auto" position throws out the channel selector buttons automatically.

The Frequency Counter measures the frequency of either the Reference Oscillator or Mechanical Reference Generator through a selector switch, and is connected directly to the Data Assembly Unit. The frequency measured is therefore that of the basic drive oscillation applied to the test piece, model, or structure and not of any incoming transducer signal.

The oscillatory reference signal passes to the Resolved Components Indicator through an additional unit known as the Reference Resolver. This can be used to introduce a manually set phase shift into the reference signal. For example, if the oscillator is used to drive an exciter through an amplifier, there may be an unwanted phase shift through the amplifier so that the force applied to the structure under test is out of phase with the reference signal. This can be corrected to within one degree by setting the Reference Resolver to indicate no phase difference when comparing the force signal with the reference signal. This correction would then be applied to all future transducer measurements.

The Oscillatory Channel Selector output passes through the Amplifier with its gain switch and to a switch with two positions, "Int" and "Ext".

The "Int" position is used unless an external switching system controlled by the Control Unit external output pulse is required. The oscillatory signal then passes to the Resolved Components Indicator where it is resolved with reference to the oscillatory drive. The Reference Oscillator output is also passed through an Amplitude Control unit to an output point for connection to an external power amplifier. An alternative to the electronic Reference Oscillator is provided by means of the Mechanical Reference Generator. This unit is used where the structure under test is forced into vibration by rotating machinery (e.g. an electric motor). A separate synchro generator, provided with the Mechanical Reference Generator, has to be mechanically coupled to the rotating shaft. The two units in conjunction then replace the Reference Oscillator in supplying the necessary reference signal. The range of rotational speed is from 0 to 3000 rev/min (50 Hz).

3.8 Console layout

Fig.7 gives a view of the Main Console. The complete equipment includes two trolleys which are designed to be placed at the right or left-hand sides of the console as may prove convenient on a site, and are equipped with plugs and sockets for connection to outlets at the sides of the console.

The console is designed so that an operator, sitting at the centre of the desk, can, without rising, reach all controls except the serial number counter on the extreme top right and the oscilloscope at the extreme top left. The most used instruments are fixed into the two centre panels. In spite of the need for this arrangement the general flow of information through the pattern of instruments is from left to right. Transducer input signals are brought in through two rows of plugs at the bottom left. The top row of these plugs is for connection to the fifty static channels and the row below it for the fifty oscillatory channels. The automatic switching units and manual switches for input channel selection are in the left hand cabinet with the observation oscilloscopes. Input signals can then be followed through to the centre panels and to the right hand cabinet which contains the control and digitizing systems. Outlets from the right hand cabinet provide links to a separate trolley on top of which the teleprinter and punch unit are fixed. Outlets from this cabinet also connect to the second trolley, which holds the analogue plotting table. The lower part of the teleprinter trolley is a storage cupboard. The lower part of the plotter trolley has a similar cupboard part of which is occupied by additional power systems for the plotter but with space for storage.

Further storage space is provided at the lower back of the right hand centre cabinet.

3.9 Mechanical assembly

A feature of the system is the ease with which it can be transferred from site to site with the possibility of fitting it into convenient corners in wind tunnel control rooms of different design. To facilitate this the main console breaks down very simply into eight cabinet sections which can be conveniently lifted. The cabinet connecting cable looms, each plug of which is numbered, can be removed as units. The desk unit is secured by single-turn screws to a light horizontal frame. The base consists of a heavier frame made of three sections bolted together.

4 OPERATION

The equipment is designed to be as versatile as possible in that any transducer providing an electrical analogue of a desired measurement can be used with it, and that the final observations can be read and recorded in analogue or digital form.

The basic mode of operation is the automatic series selection, digitizing and printing of the analogue transducer signals which has already been described. The resultant list of numbers may be of little value in itself being merely a record of the parameters existing for one particular set of conditions. In experimental work it is often necessary to obtain a series of such records related to prescribed variations in one of the parameters (e.g. drive frequency). The punched paper tape produced in parallel with the printed format could then be used as the input to a digital computer for analysis of the whole series of events. Suitable programs have been written for the recognition and conversion of the multiplier symbols which appear before each measurement and for the selection of the output of a particular oscillatory transducer and the vector plotting of its in-phase and quadrature components using the computer's on-line digital plotting table. The possibility of producing a variety of other programs for some specified application is obvious.

The plotting table and digital print-out may be used in parallel. The plotting table will then follow the analogue output of the resolved components indicator for each transducer in turn. It will only plot a point when the separate "Plot" button is pressed and can therefore be used to make a vector plot of the response of one or more of the oscillatory transducers as the drive frequency is altered in steps.

Frequently only a few transducers are used and the full digital print-out is not required. It may then be inhibited by allowing the system to run through to the block of oscillatory readings and pressing the "Infinite" button. Transducers may then be selected on the Manual Selection panel and the response plotted for each separately as the frequency is changed.

Fig.8 shows the equipment in use with ancillary equipment, in plotting the modes of oscillation of a model T-Tail. Capacitor proximity guages are fixed at suitably chosen points near the surface of the model. The gauge leads are brought together at a motor-driven rotary switch designed for low-capacity switching. The switch is linked to its own controlling and indicating unit and to a unit which converts change of gauge capacity into a voltage signal. Selection of gauge through the rotary switch system is made by an initiating pulse from the main control console and voltage signals are fed into the external input point on the console (see Fig.1). The model is vibrated through a power amplifier from the console oscillator. Measurements of the in-phase and quadrature components of the model response at each gauge position are punched out on tape or plotted on the analogue X-Y plotter as required by the operator.

5 LIMITATIONS AND ACCURACIES

All input lines have two connections - high and low level. The maximum voltage which can be applied to the static input points is 200 volts, with a proviso that the low side must be held to within 6 volts of earth potential. As these inputs are passed directly to the digital voltmeter, the maximum sensitivity can be quoted as 10 microvolts. This is the last digit of the most sensitive voltmeter scale but, in fact, contact potentials and setting-up errors cause random flicker of this digit. Accuracy, therefore, will not be better than 1% for input voltages below 1 millivolt.

For the oscillatory channels the maximum input voltage is 150 volts rms. This would be switched directly to the input of the Resolved Components Indicator. The minimum usable signal when including the pre-amplifier in the circuit is 5 microvolts. The amplifier gain is switched in steps and it should be noted that, if the input signal is large and the amplifier gain switch is set so that its output swing exceeds ±10 volts, the amplifier will be overloaded and will take several seconds to recover. During this period the gain will be zero or very small.

The maximum frequency range of the system is from 0.01 Hz to 10 kHz. Within the range 0.5 Hz to 1 kHz errors for in-phase and quadrature readings are approximately 0.1%. The input attenuator of the Resolved Components Indicator was modified to make this attainable. Outside this frequency range, a progressive reading error appears. A calibration curve supplied by the manufacturer can be consulted to correct for this.

An assembly of complex electronic instruments such as this presents the possibility of failure or incorrect working of some part of the system. Such failures should not make the whole system unusable. A separate wired-up input plug and cable is stored in the console for checking all input lines and switches. Using this, a dc supply can be connected to the static input points and each line checked by manual or automatic switching to the digital voltmeter. In a similar way an oscillatory signal from the Reference Oscillator can be fed to the oscillatory input points and each selector switch checked by reading the output of the Resolved Components Indicator. The digital voltmeter and frequency counter have self-checking facilities on their front panels. The Resolved Components Indicator can be checked by connecting phase output points from the Reference Oscillator to its input terminals. The checking systems for these instruments are detailed in their respective instruction manuals.

All instruments except the Resolved Components Indicator can be directly replaced by the standard commercial items of the same type number. The Resolved Components Indicator has been modified by the inclusion of an additional switch segment on the input attenuator switch. This segment provides the second multiplier symbol for the oscillatory measurements in the print-out. This, and specified resistor selection made to improve the input attenuator accuracy, means that replacing this instrument by the standard commercial model would result in a slight loss of accuracy and the omission of the factor symbol from the print-out.

Should it be necessary to remove the Frequency Counter from the system the automatic control will run through to the frequency count and stop. It cannot proceed until a "frequency count complete" signal has been received.

To overcome this a switch has been incorporated at the rear of the Control Unit rack to allow the run to continue with the frequency count omitted.

As the digital voltmeter is the heart of the system an identical spare unit is held and used for general measurement purposes. The Control Unit itself is constructed in the form of plug-in component cards of several types. Spare cards are stored in the rear of the console.

6 CONCLUDING REMARKS

The equipment has been used on several major projects in widely separated locations since its completion. The mechanical breakdown system has proved to be a valuable asset in handling for transport and the instruments sufficiently robust to withstand long journeys. The speed and efficiency with which results can be obtained during a wind tunnel model test series justify the bringing together of the many components into a single ergonomically-designed unit.

Acknowledgements

The author thanks Mr. Clive Leedham of I. & R. Department, R.A.E. for his advice and assistance, and Mr. Peter Brett of MEL Ltd., who was responsible for construction and commissioning.

Appendix

Component	Type No.	Manufacturer
Control system	-	MEL Equipment Co. Ltd., Manor Royal, Crawley, Sussex.
Oscilloscopes	CD 1400	The Solartron Electronic Group Ltd., Victoria Road, Farnborough, Hants.
Reference Oscillator	OS 103 3	- do -
Resolved Components Indicator	VP 2533	- do -
Reference Resolver	JX 746 2	- do -
Mechanical Reference Generator		- do -
Digital Voltmeter	DM 2005	Dynamco Ltd., Hanworth Lane, Chertsey, Surrey.
Frequency Counter	SA 540	Racal Instruments Ltd., Crowthorne, Berks.
Amplifier	Redcor Model 361	Benson-Lehner Ltd., West Quay Road, Southampton, Hants.
X-Y Plotter	Model 20170	Bryans Ltd., Willow Land, Mitcham, Surrey.
Teleprinter	Model 75	Creed and Co. Ltd., 8 Hinde Street, London, W.1.
Tape Punch	75 attachment	
Tape Winder	-	

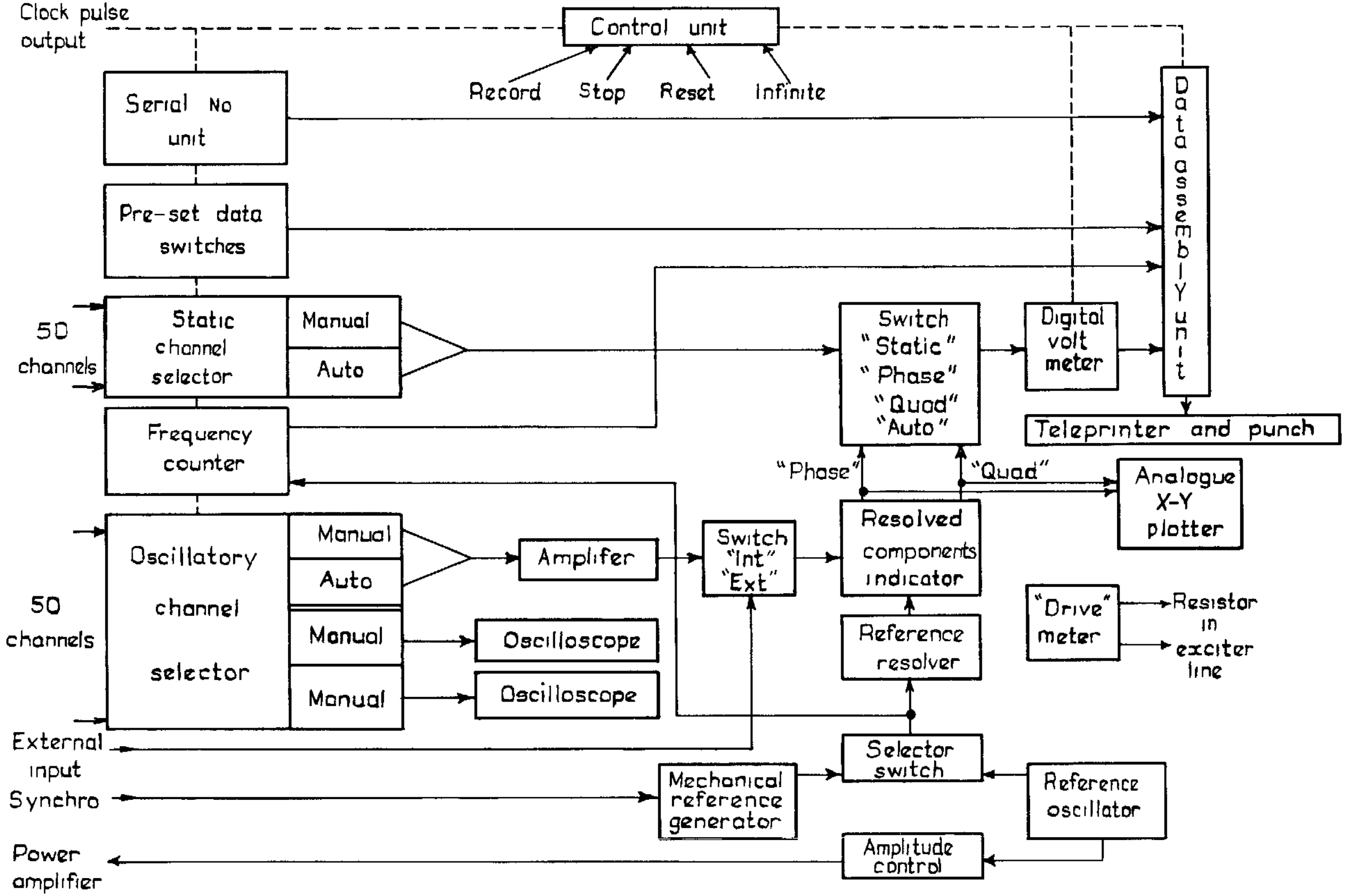

Fig. 1 Block diagram

Tape	N	Printer	
		Figs	Lets
·	0	Fig	Shift
· ●	1	1	A
·●	2	2	B
·●●	3	*	C
●·	4	4	D
●· ●	5	(	E
●·●	6	)	F
●·●●	7	7	G
● ·	8	8	H
● · ●	9	≠	I
● ·●	10	=	J
● ·●●	11	—	K
●●·	12	V ≃	L
●●· ●	13	L.F.	M
●●·●	14	Sp	N
●●·●●	15	,	O
● ·	16	0	P
● · ●	17	>	Q
● ·●	18	≥	R
● ·●●	19	3	S
● ●·	20	→	T
● ●· ●	21	5	U
● ●·●	22	6	V
● ●·●●	23	/	W
●● ·	24	x ψ	X
●● · ●	25	9	Y
●● ·●	26	+	Z
●● ·●●	27	Let	Shift
●●●·	28	•	•
●●●· ●	29	n '	?
●●●·●	30	C.R.	£ π
●●●·●●	31	Ӿ	Ӿ

Fig. 2 Mercury teleprinter code

```
        ≠≠
RUN
0008
0025  0004  1968  0000  0000  0000
0800  1520  1105  0000  0000  0000

2  -1235  2  -1531  3  -0161  3  -0125  3  -0124
3  -0125  3  -0120  3  -0124  3  -0113  3  -0123
3  -0112  3  -0123  3  -0111  3  -0122  3  -0111
3  -0122  3  -0110  3  -0121  3  -0108  3  -0116
3  -0109  3  -0122  3  -0108  3  -0121  3  -0103
3  -0124  3  -0108  3  -0122  3  -0105  3  -0121
3  -0107  3  -0124  3  -0116  3  -0121  3  -0119
3  -0124  3  -0118  3  -0001  3  -0042  3  -0119
3  -0084  3  -0118  3  -0133  3  -0115  3  -0104
3  -0114  3  -0130  3  -0117  3  -0117  3  -0117
*

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443   0082  443   0123  443   0124  443   0142
443   0480  443   0037  443   0690  443   0872
443   0927  443   0799  443   0730  443   0605
443   0482  443   0493  443   0323  443   0422
443   0224  443   0327  443   0139  443   0191
443   0019  443  -0007  443   0025  443   0075
443   0079  443   0077  443   0178  443   0137
443   0442  443   0775  443   1071  443   0795
443   0777  443   0108  443  -0138  443   0045
443   0261  443   0266  443   0250  443  -0036
443   0256  443   0000  443   1167  443   0988
443   1134  443   0839  443   0855  443   0612
443   0381  443   0354  443   0402  443   0299
443   0311  443   0242  443   0088  443   0113
443   0087  443   0108  443   0096  443   0551
443   0762  443   0830  443   0980  443   0892
443   0819  443   0694  443   0602  443   0517
443   0439  443   0398  443   0297  443   0281
443   0200  443   0200  443   0144  443   0154
443   0115  443   0119  443   0091  443   0105
443   0093  443  -0233  443   0700  443   0006
443  -0027  443   0053  443   0003  443   1854
443   0281  443   0607  443   0150  443  -0411
443  -0138  443   0026  443   0030  443   0157
443   0031  443   0214  443   0010  443   0237


→
*******
```

Fig.3 Output format

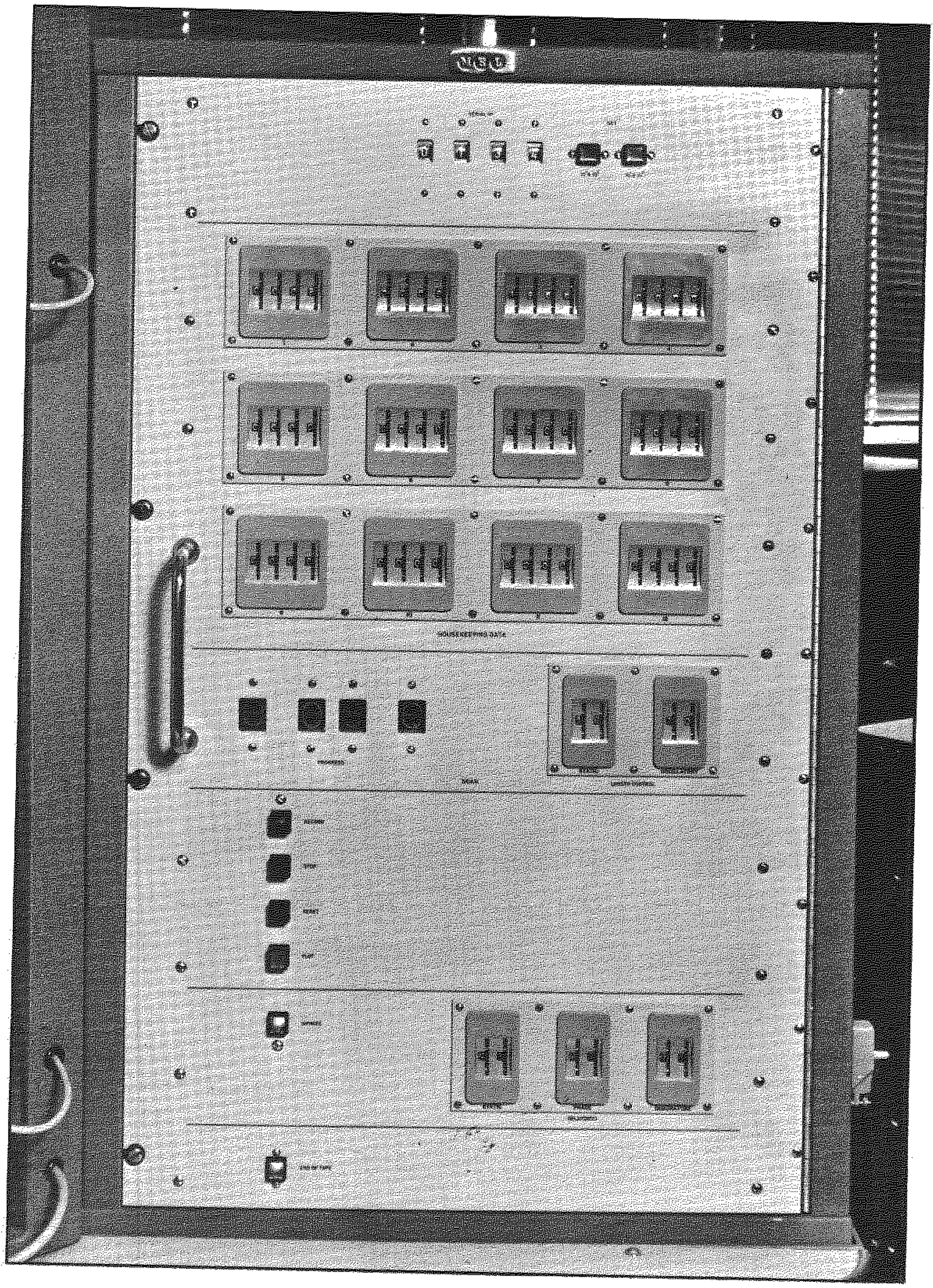

Fig.4 Control panel

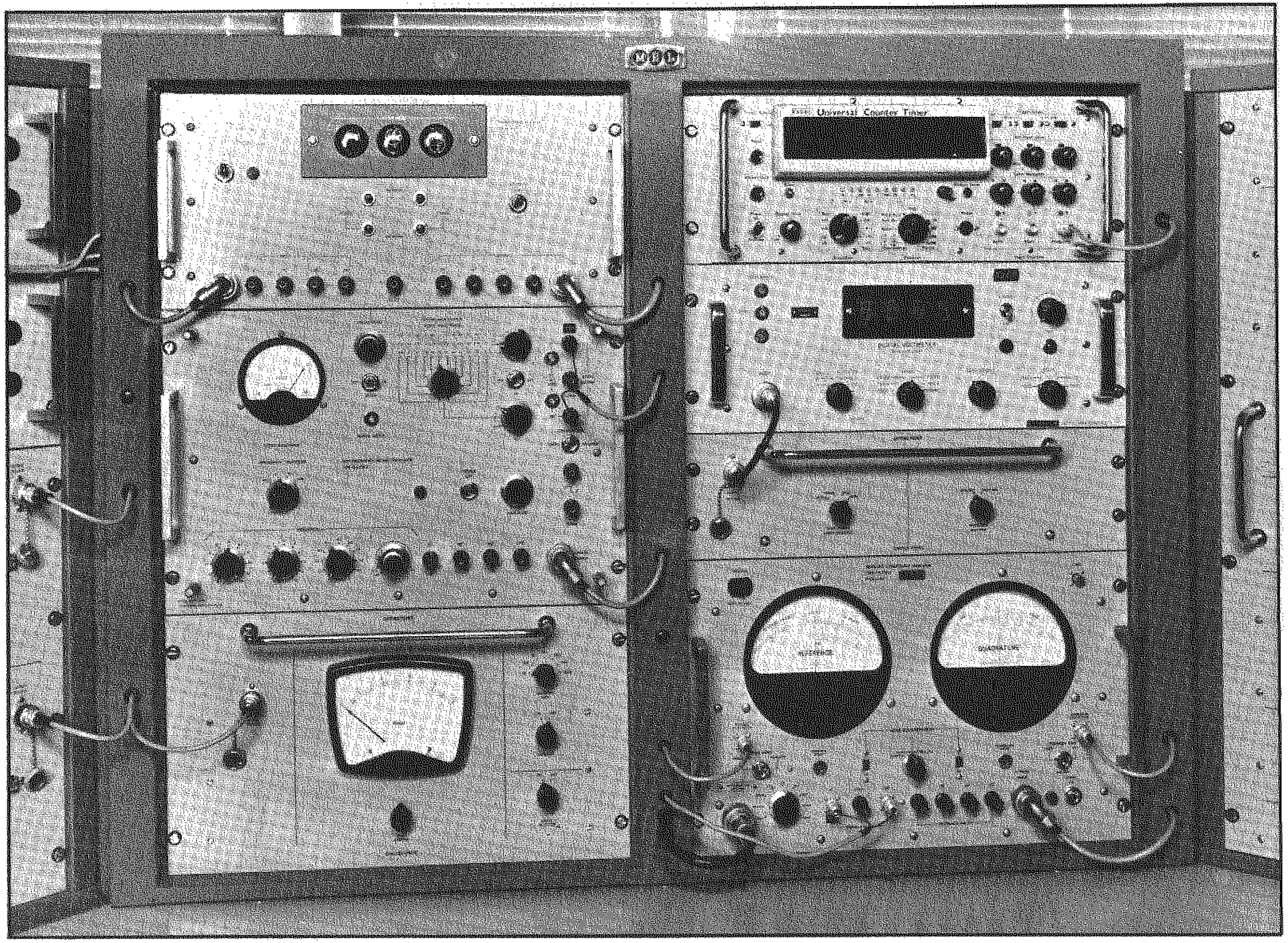

Fig.5 Centre instrument panels

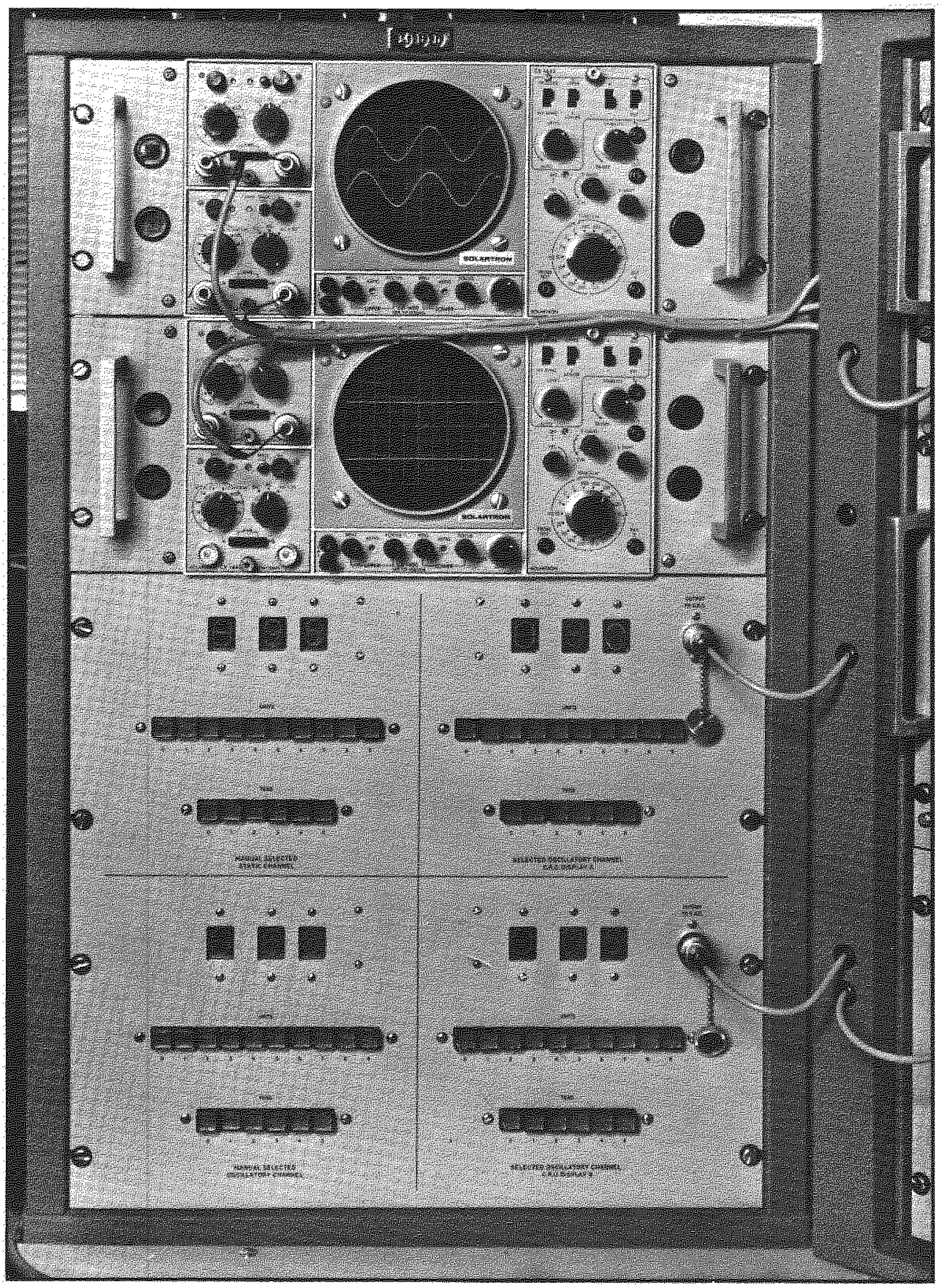

Fig.6 Manual switch panel

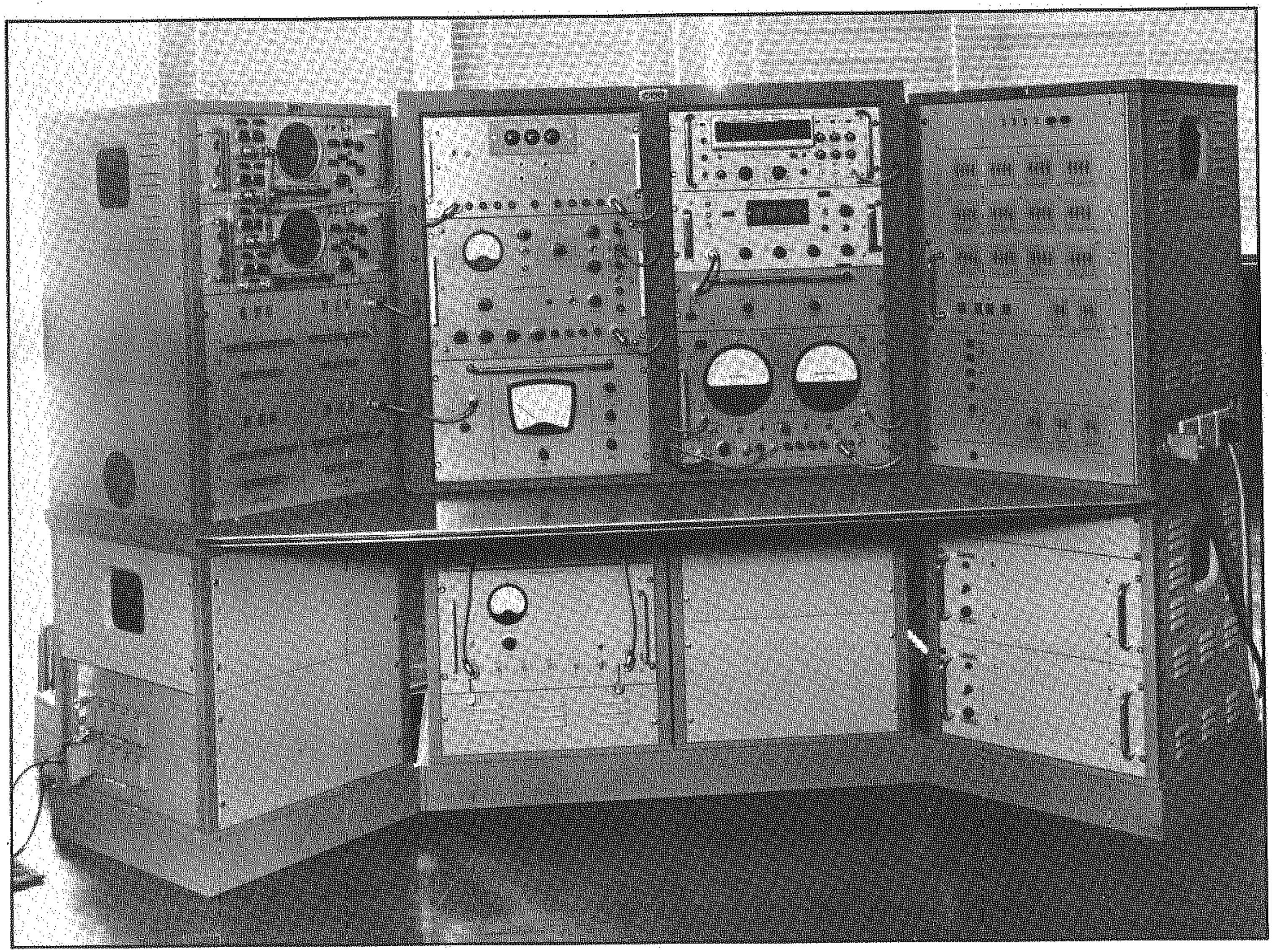

Fig.7 Main console

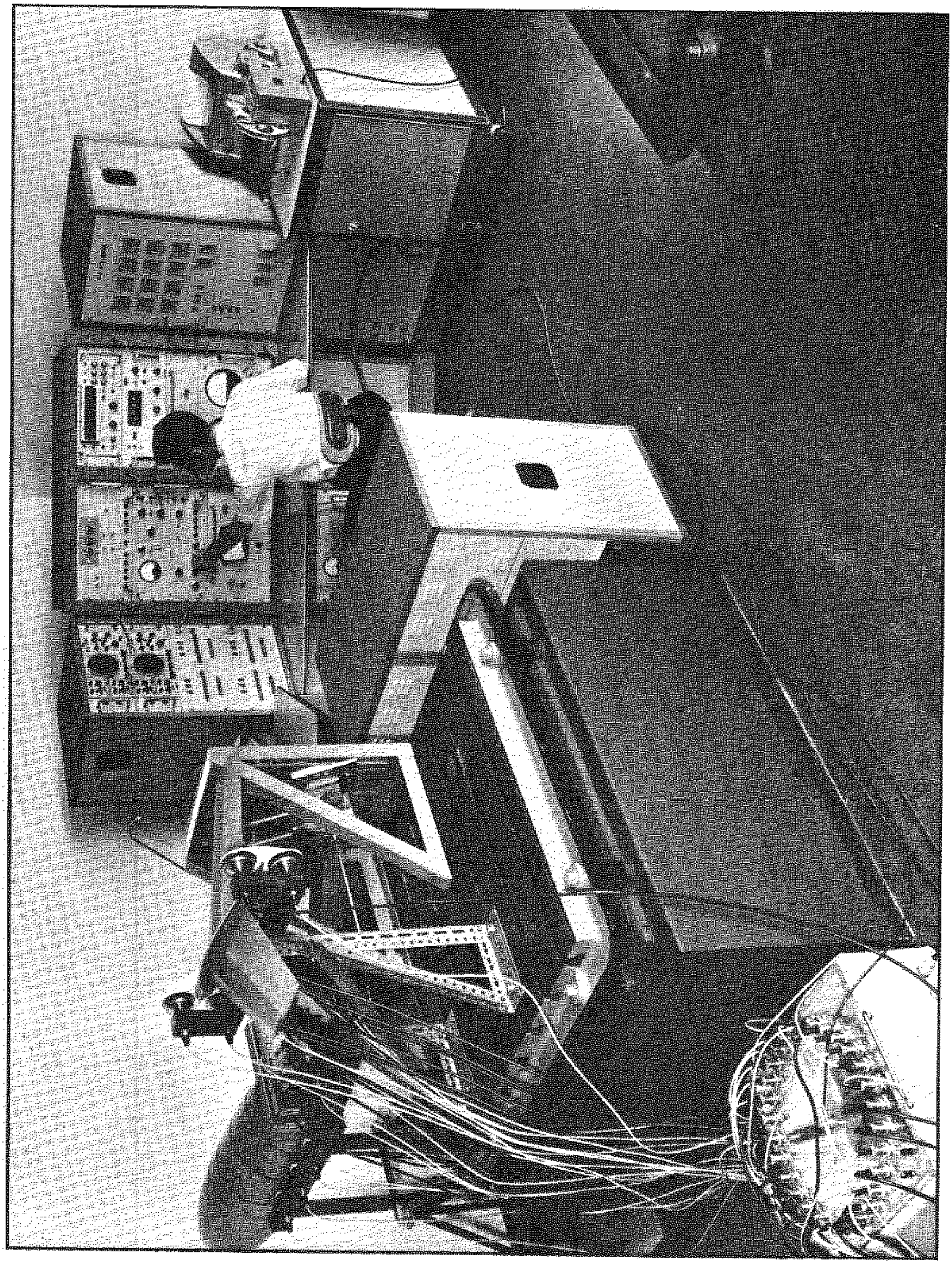

Fig.8 Resonance testing a flutter model

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The system can be programmed to handle, automatically, sequences of input data and, after analysis, to output the data in printed form and on punched paper tape. Graphical presentation of analysed oscillatory data is provided.

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DETACHABLE ABSTRACT CARDS

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