THE COLLEGE OF AERONAUTICS, CRANFIELD

DEPARTMENT OF PRODUCTION ENGINEERING

Grinding Cycle Control Project 1967

Project Members

Students

G.C. Boshier
W. Morrison
G.W.H. Pike
E.A. Powell
R.S. Sutcliffe
R. Veazey

Staff

C.J. Charnley
R.E. Bidgood
S. Ramanathan

Summary

An investigation has been made into the sequential control of a grinding machine using electro-pneumatic, ball valve and wall attachment switching elements. Each system has been tested on a grinding cycle simulator and also to a limited extent when applied on a grinding machine. A technical assessment has been made of each system.

In the case of the pure fluid system it was necessary to design and build an amplifying and switching circuit before the tests could be carried out and reports are presented of these investigations.

Grinding Cycle Control Project

1.0. INTRODUCTION TO THE PROJECT

Technology is advancing at a rapid rate, and because of this there is an increasing demand for certain engineering components to be manufactured to closer tolerances. In general, this requirement is reflected in much greater complexity (and hence cost) of the control systems which are governing the operation of machine tools, but it was thought that the advent of fluidic devices would enable a new approach to be made.

The department has been investigating precision grinding techniques for a number of years using an electro-pneumatic 3 stage sequential controller operating on a Studer precision grinding machine. Investigations were also proceeding into the behaviour of fluidic elements, both moving part and non-moving part, and their suitability for machine tool applications and it was recognised that an attempt to apply them to grinding control would enable useful comparisons to be made.

Accordingly, in 1964, the grinding machine was fitted with a Kearfott ball valve system following a thesis on the characteristics of these units by Bidgood (1). The analysis of the results on the grinding machine are presented in another report by Charnley and Bidgood (2).

The initial stage of the project was to determine the feasibility of reproducing the 3 stage sequential switching action using pure fluid elements and then to design and build a control system to be operated in parallel with the other 2 systems. This investigation was carried out and the system demonstrated to operate successfully on a grinding cycle simulator and on the grinding machine.

The primary object of the project was to evaluate and compare technically, and as far as possible, economically, the performance and accuracy of the 3 systems, electro-pneumatic, ball valve and pure fluid, under simulated and actual grinding conditions. The initial specification was to produce ground specimens to within a tolerance of $\pm 20 \times 10^{-6}$in. (0.5×10^{-3}mm). To achieve this order of accuracy the surface finish has to be in the order of 1×10^{-6}in. (0.25×10^{-3}mm) and the roundness better than 10×10^{-6}in (0.25×10^{-3}mm). It will be seen later that all 3 systems are capable of switching to within $\pm 10 \times 10^{-6}$in (0.25×10^{-3}mm) when operating on the grinding cycle simulator test rig but unfortunately difficulties were encountered in maintaining roundness during the actual grinding tests and it was not possible to overcome these difficulties in the time available. However, the results obtained on the simulator enabled a full assessment to be made of the performance of the switching systems and the comparisons are presented below.

2.0. DESCRIPTION OF GRINDING MACHINE AND GRINDING CYCLE SIMULATOR

The precision grinding machine and control equipment used for the grinding tests is shown in Fig. 2.1. The control system operates on a closed loop basis, fig. 2.2, with intermittent feedback at the preset tolerance bands at which the coarse/fine feed, fine feed/sparkout and stop/withdraw grinding wheel changeover signals are initiated. Measurement is continuous, during machining, by an air gauge on the component which is the best place to give optimum overall control; the recorder does not operate in the control loop but is fitted to enable a continuous record to be kept of the operation and as a check on the performance of the control system. The control element converts the measured signal into an error signal, performs the required sequential logic operations, initiates the various rates of feed and finally withdraws the grinding wheel in the operating sequence illustrated in fig. 2.3.

After careful evaluation of all the basic control operations it was found that the complete system for the control of the machine would require 12 logic units, 3 high accuracy limit switches, 1 pneumatic gauging unit and a selection of on/off valves. The success or failure of the system depends entirely on the sensitivity and repeatability of the three high accuracy limit switches and therefore this part of the problem was investigated first.

Before applying the control systems to the machine it was decided to carry out a series of tests using a grinding cycle simulator test rig as shown diagramatically in fig. 2.4. The grinding cycle was simulated by means of a motor driven micrometer screw set to reduce the air gauge gap at the normal grinding feedrate. The output from the final size limit switch was fed into a transducer which in turn operated the solenoid and disengaged the motor drive at the preset size.

Using this method it was possible to test the limit switch for repeatability by pre-setting a gap (or size) at which the logic unit would trigger and cut off the drive, allowing the unit to switch, and then repeating the process several hundred times. Each of the elements investigated - electro-pneumatic, ball valve, and wall attachment - was tested on the simulator to determine its inherent performance prior to tests on the grinding machine.

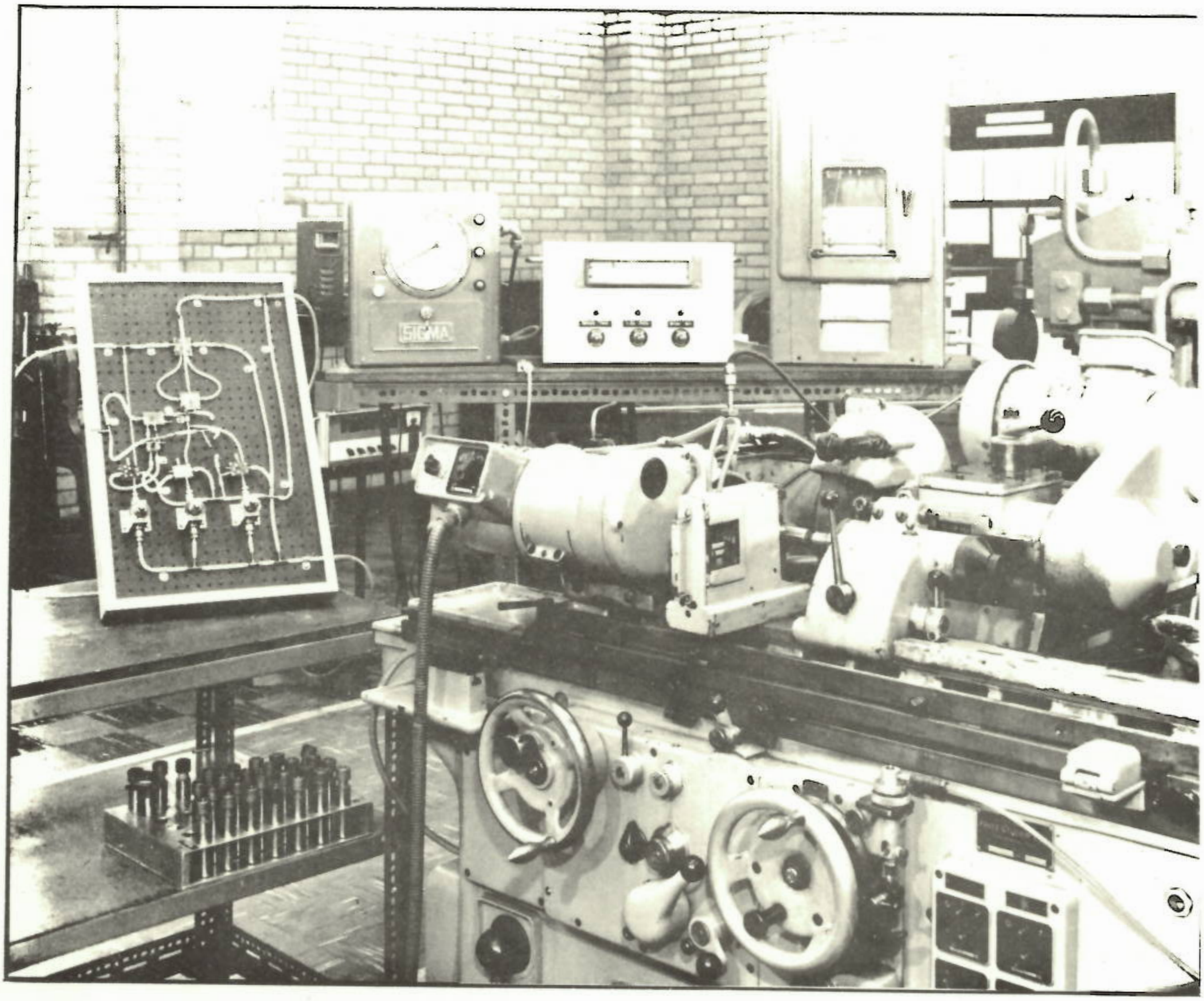


FIG. 2.1. Precision Grinding machine and control equipment. The units mounted at the rear of the machine are, from left to right, the wall attachment, electro-pneumatic and ball valve control systems, and the specimen size recorder.

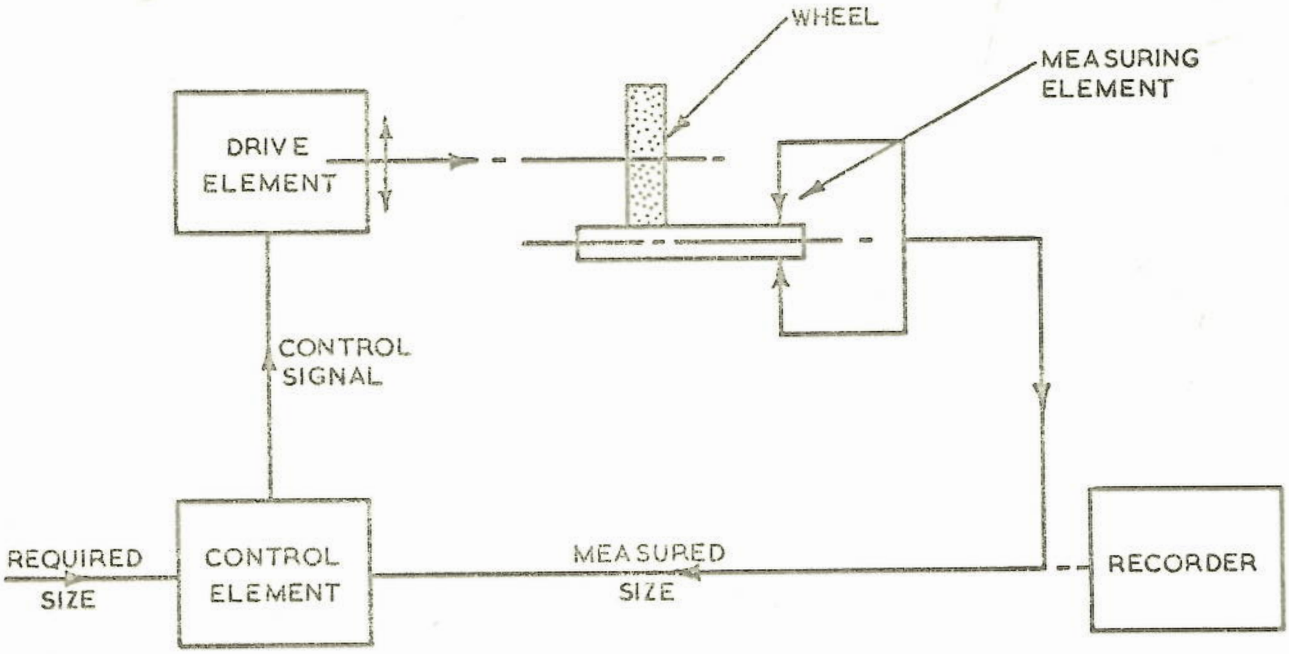


FIG.2.2. CLOSED LOOP SYSTEM FOR GRINDING CONTROL.

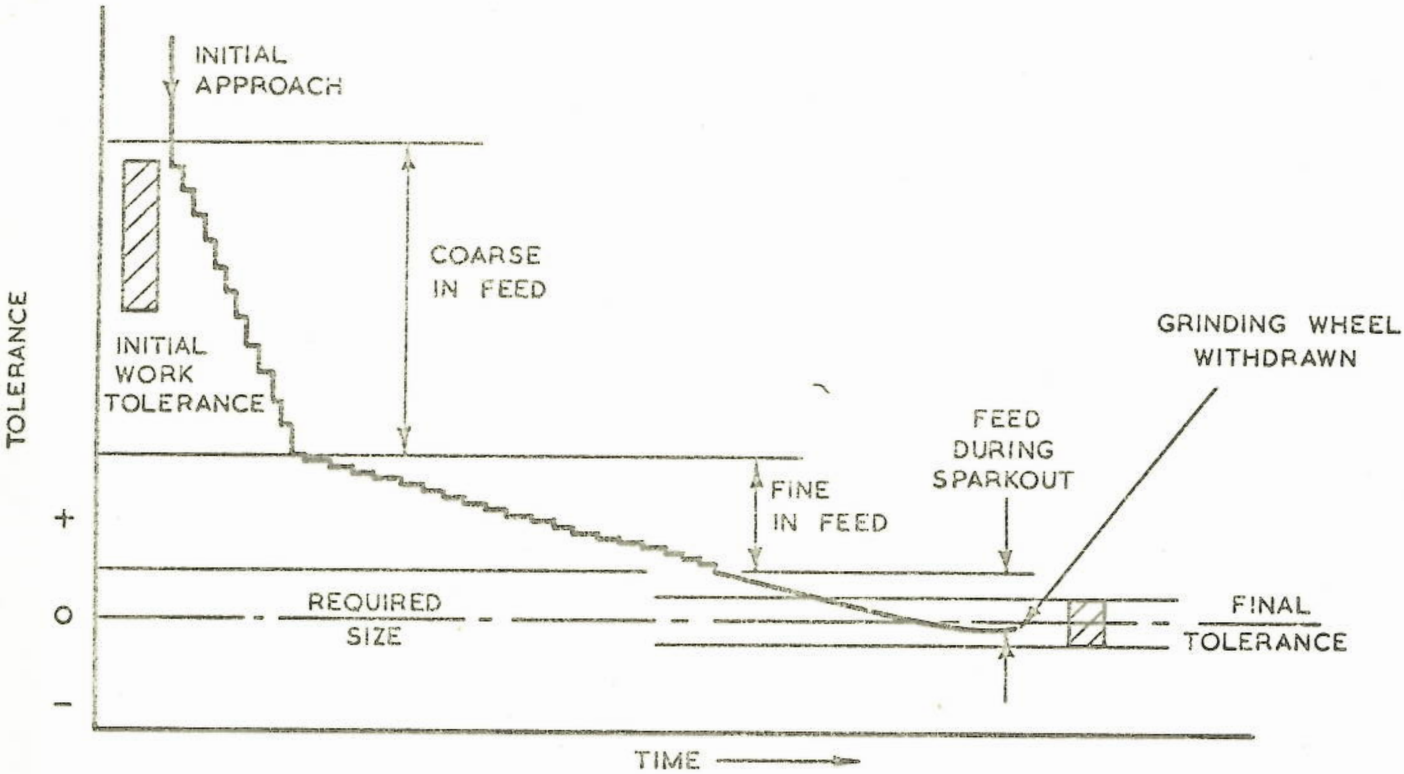


FIG.2.3. AUTOMATIC OPERATING SEQUENCE.

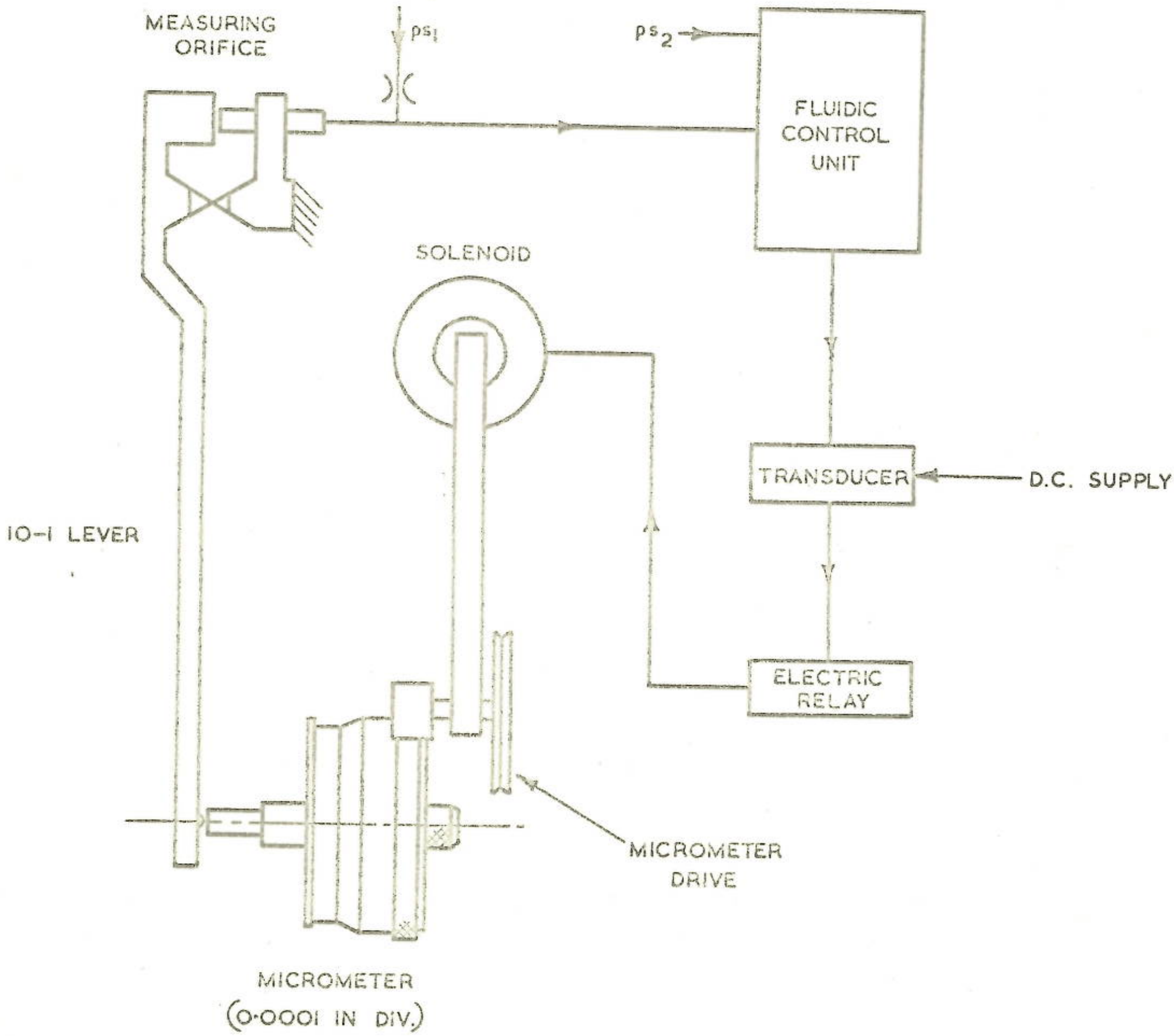


FIG. 2.4. GRINDING CYCLE SIMULATOR TEST RIG.

3.0. ELECTRO-PNEUMATIC SYSTEM ASSESSMENT REPORT

prepared by - R. Sutcliffe
R. Veazey

Terms of Reference

To investigate the operation of an electro-pneumatic 3 stage sequential switching system. To obtain the repeatability of a specimen size from a given master and also to estimate production and operating costs.

3.1. Description of Circuit

Measurement of component size was made by a special air gauge, designed by a Cranfield student for use on precision grinding machines. The electro-pneumatic controller used was a special three stage SIGMATROL unit, designed and manufactured by the Sigma Instrument Company Limited, Letchworth, Herts. The SIGMATROL system requires both a 240 volt electric mains supply and an 80 lbf/in^2 compressed air supply and can operate with either a caliper or mandrel gauge. When used in conjunction with a caliper gauge it functions as follows - refer to fig. 5.1.

On entering the unit the high pressure air supply is divided into two separate circuits, one supplies the caliper gauge and electro-pneumatic transducer (UA 541), the other supplies the pressure gauge which acts as the component size indicator; both these circuits are connected to a pneumatic amplifier.

From the high pressure air supply the first circuit feeds into a pressure regulator before dividing into two arms, the first of which supplies the caliper gauge through a restrictor, which also acts as a non return valve. The second arm passes the air through another non return valve restrictor to a bleed valve which also acts as a setting valve for calibration (ZERO VALVE). From this valve the supply is then divided three ways so as to pressurise one side of three individual units, these being :

a) ELECTRO-PNEUMATIC TRANSDUCER (UA 541)
b) SPECIAL CONTROL VALVE (FINE OVERSIZE)
c) PNEUMATIC AMPLIFIER

The second circuit, which is the control circuit, operates on a lower air pressure than the first. The supply feeds the calibrated pressure gauge, through a restrictor together with the caliper gauge and also the opposite side of the pneumatic amplifier and electro-pneumatic transducer, to that supplied by the first circuit.

The pressure in the first circuit remains constant throughout the complete operation, whilst the second circuit has a pressure build up that varies proportionally as the caliper gauge closes thus preventing the air from escaping to atmosphere. This gives a changing pressure differential between both sides of the pneumatic amplifier and electro-pneumatic transducer.

The pneumatic amplifier increases the pressure in the pressure gauge, which then gives the operator a visual indication of the components size.

The electro-pneumatic transducer is designed to give a signal for three separate component sizes, these electrical signals are connected through electro-mechanical relays to the wheel head infeed and retract mechanisms.

The first signal operates when the component is 0.000 3in above its required size, this stops the wheel head from operating on coarse feed and the signal switches it to fine feed.

The second signal operates when the component is 0.000 1in above its required size and stops the wheel head from feeding into the workpiece whilst allowing the machine to continue to spark out.

The third and final signal operates when the component has been ground to its required size; it retracts the wheel head on the completion of the pass being made when the final size signal was given.

To give the operator a visual indication of each signal three differently coloured lights are positioned with the calibrated pressure gauge. These lights also act as warning lights in case of malfunctioning by the automatic system, thus enabling the operator to manually operate the retraction mechanism before the component has been ground undersize.

3.2. Repeatability on Test Rig.

The repeatability of the SIGMATROL unit was evaluated on the grinding cycle simulation rig.

A 0.125in gauging nozzle was used for the first series of test, and the results of 200 readings are shown in fig. 3.2a. It can be seen that with the 0.125in gauging nozzle in use, the SIGMATROL unit switched off at two distinct nozzle gaps. This was due to a random switching error causing the 'retract' signal to occur at the end of the fine-feed operation.

The test was repeated using a 0.062in diameter gauging nozzle, and the results of 100 readings are shown in fig. 3.2b.

3.3. Performance on Grinding Machine

The centres of the grinding machine were ground, and the grinding wheel was dressed at the start of each test. The coolant and refrigeration unit were switched on 12 hours before the tests. The results for the first series of tests are shown in figures 3.3. to 3.7., the main readings having been taken after the specimens had been kept a constant temperature of 68° for 24 hours. Diameters were measured on a precision micrometer at the centre of the specimens, and out of roundness measured at the same point using a 'Talyrond' roundness tester. The surface finish was measured using a Talysurf, giving C.L.A. readings in micro-inches.

Figure 3.3a. shows that the variation in diameter of the specimens was 0.001 inches. There appears to be a downward trend in diameter in the order of grinding, due in all probability to changes in ambient temperature during the grinding test.

Figure 3.3b. shows that the out of roundness of the specimens varied from 10 to 40 micro-inches. Thus all 12 specimens fell outside the prescribed limit of 10 micro-inches.

The surface finish (see fig. 3.3c) was satisfactory with a maximum value of 2.5 micro inches C.L.A.

As it was suspected that the out of roundness might be due to the heat treated case having been ground off the specimens, a new batch of 12 specimens with full case thickness was ground. The results were similar to the first test, a variation in diameter of 0.001 5in and an out of roundness of up to 70 micro-inches indicating that no improvement in accuracy had been achieved. On this test, the Sigmatrol unit was calibrated against the master, and was found to have drifted from the zero setting by 60 micro-inches.

Although no attempt was made to control the taper of the specimens, a number of measurements were made to assess the variability of this part of the process. It was found that the taper varied between 32 and 45 micro-in per inch.

3.4. Economics

As stated in 3.1., the SIGMATROL is a proprietory unit that has been designed by the Sigma Instrument Company for use on a precision grinding machine, and as such the purchase price was £300 ($837). From the blue print supplied (drawing no. WD 263) it can be seen that the unit consists of certain standard pneumatic components together with standard electrical plugs, sockets and relays.

Relays have proved themselves to be robust for work in automatic control units, their only disadvantages being that they have moving parts and the unit could fail due to contamination on the relay contacts. Because of the unit construction the latter point would not be so serious as replacement units could be substituted for any damaged or non-functioning unit.

The SIGMATROL unit itself has been used at the College of Aeronautics for many years on various precision grinding machines and has operated satisfactorily. Servicing and fault finding with the unit could be expensive after the unit has been operating for a number of years, due to wear of the moving parts, relays, switches, etc.

The complete SIGMATROL unit is relatively compact and could be readily fitted to most precision grinding machines.

3.5. Conclusions

The repeatability tests showed that the Sigmatrol unit gives a repeatability of ± 5 micro-inches on diameter, provided that a nozzle of the correct sensitivity is used.

The grinding machine tests showed that the inaccuracies in the Studer grinding machine are so high as to render comparison of performance of gauging systems of the same accuracy as the Sigmatrol unit impossible.

The out of roundness of specimens must be overcome before comparison of gauging systems is possible. The accuracy of the grinding machine and specimen centres, and the balancing of the grinding wheel will be of great significance in this respect. The drift at the zero setting of the Sigmatrol unit is also a great inconvenience if large batches of specimens are to be compared.

Greater control of the ambient temperature during grinding tests should be exercised by siting the Studer in a temperature controlled environment

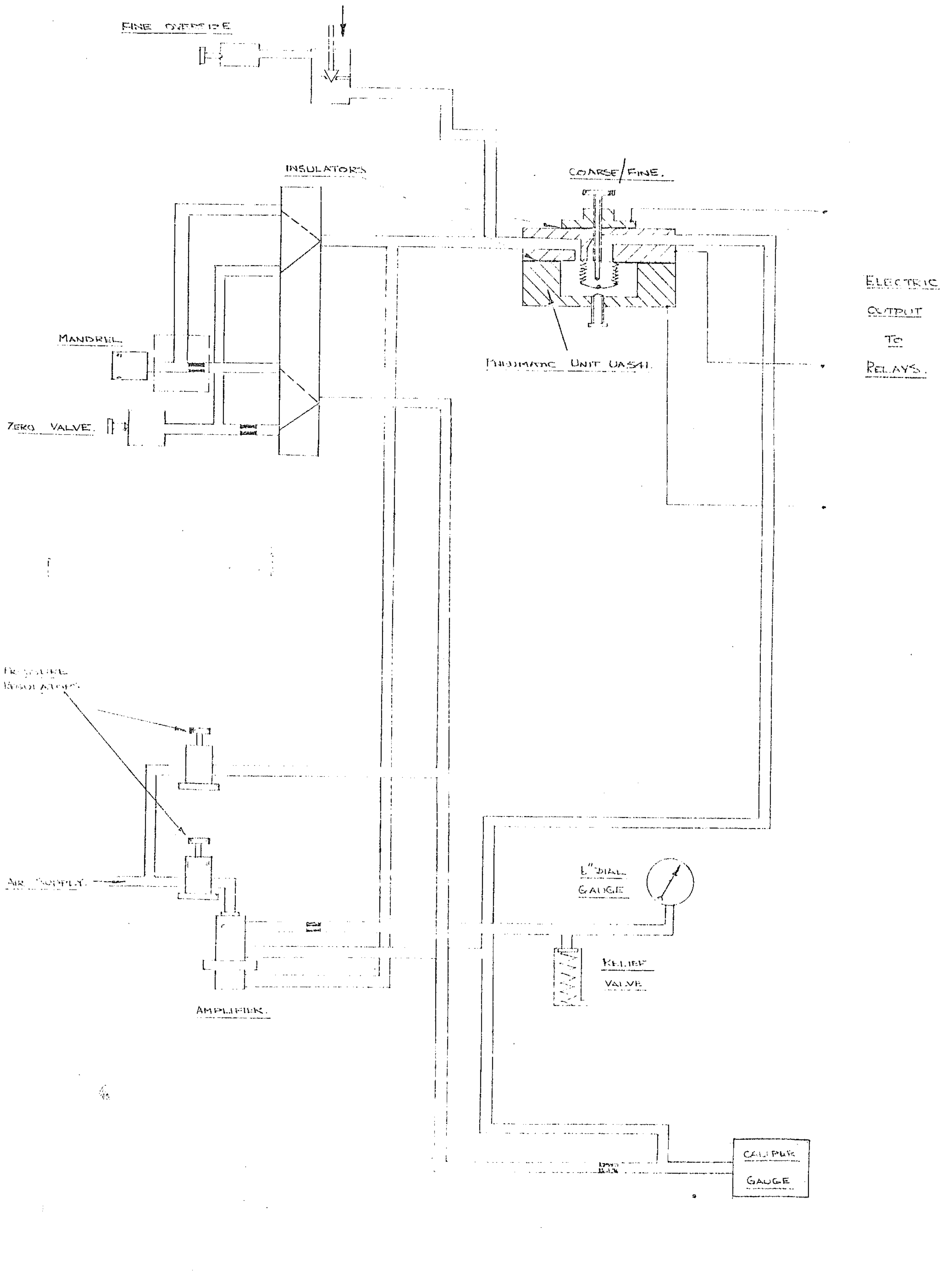
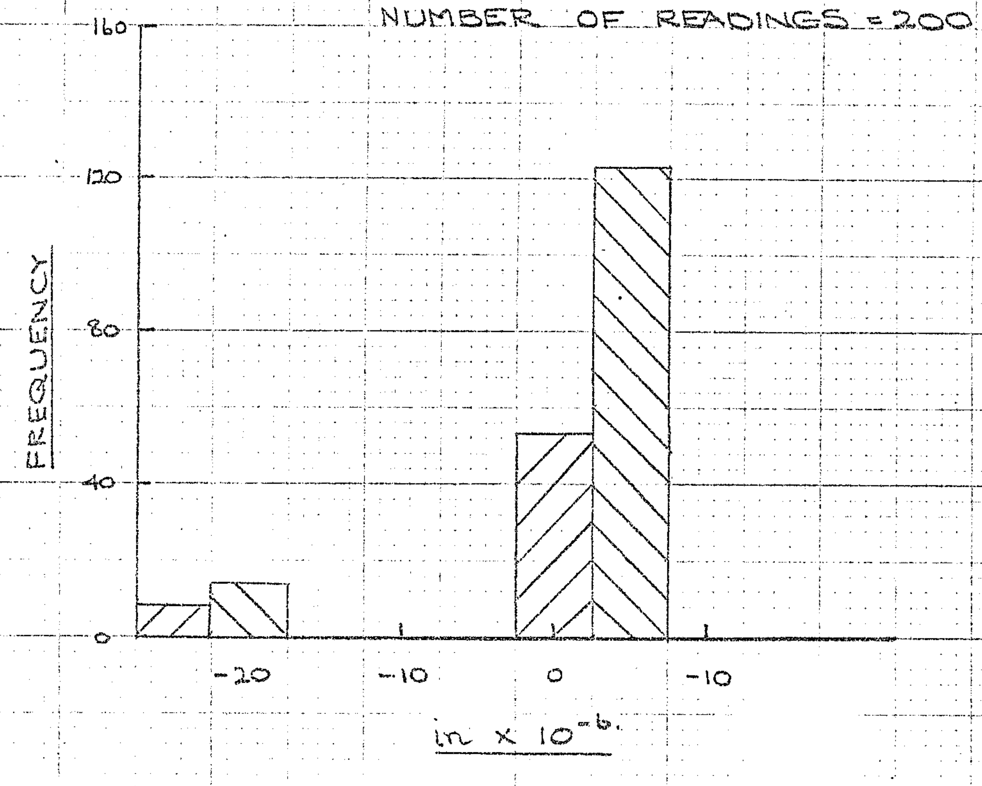
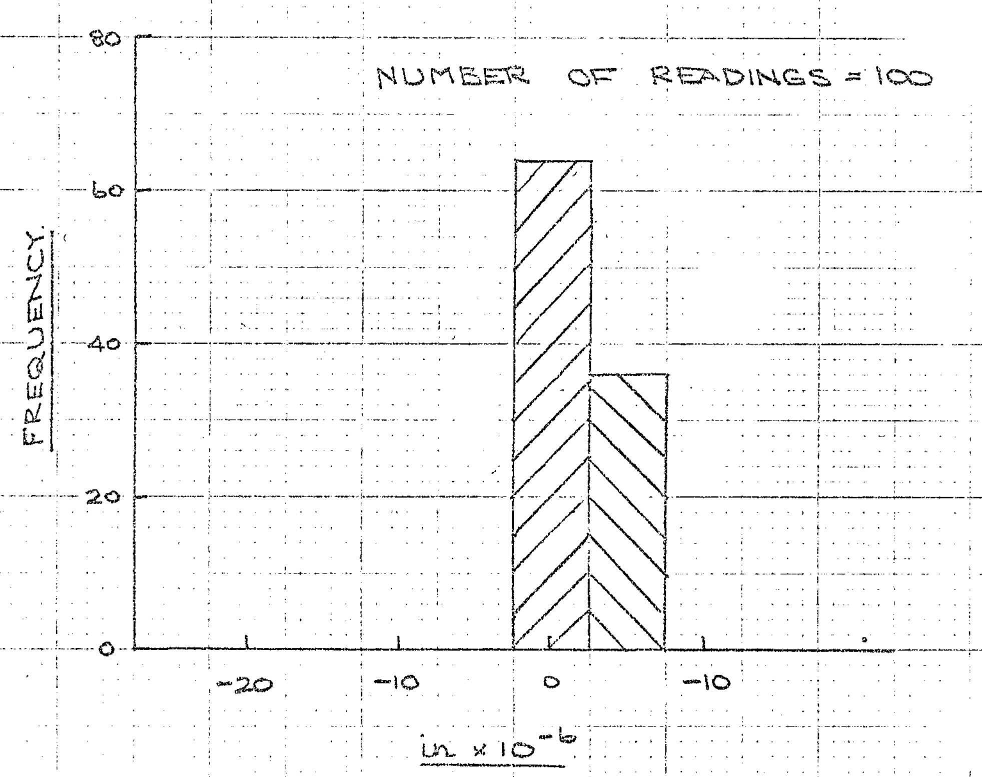


FIG. 3.1. ELECTRO - PNEUMATIC CONTROL CIRCUIT.

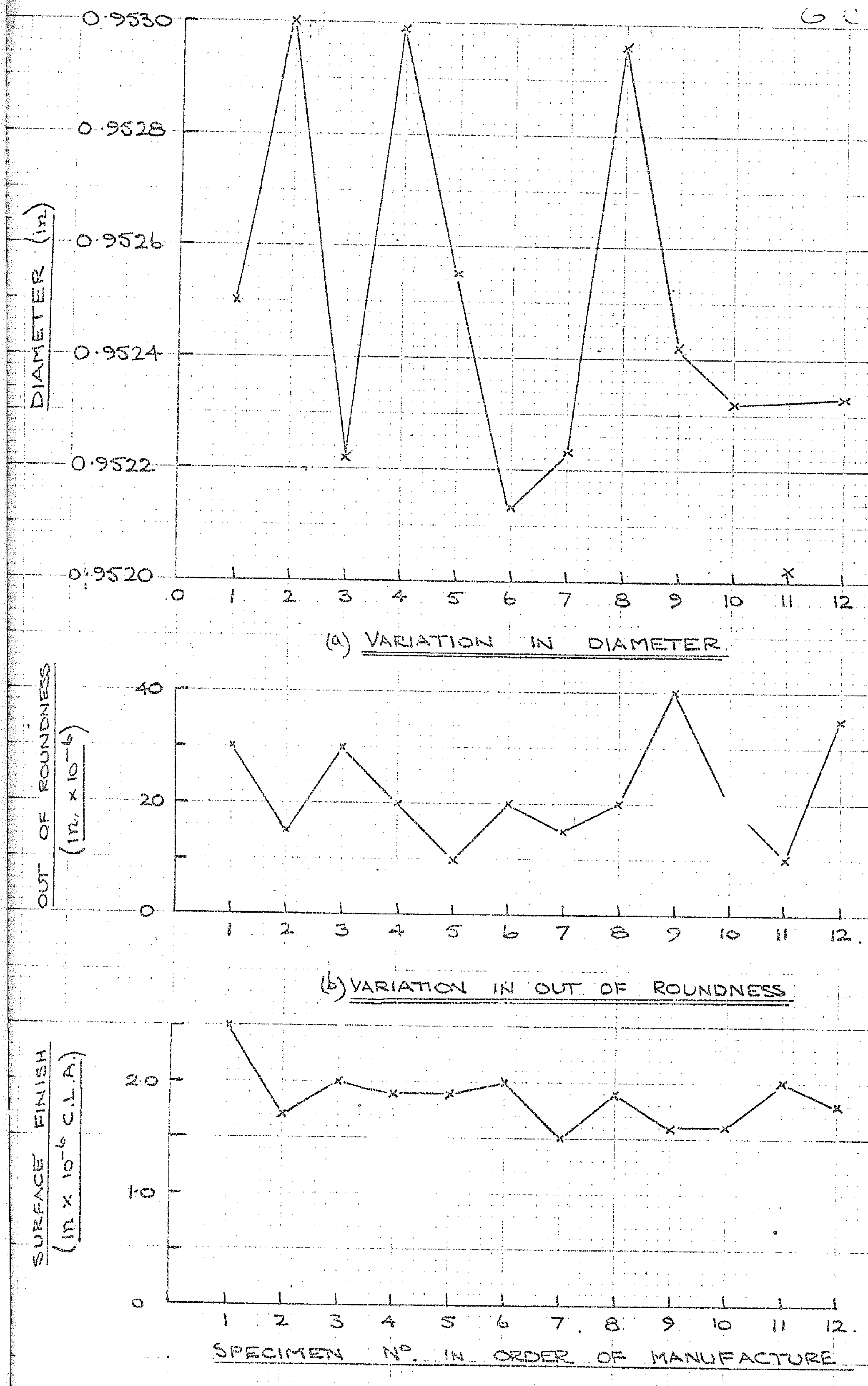


(a) NOZZLE DIA. 0·125 in.



(b) NOZZLE DIA. 0·062 in

FIG. 3.2. REPEATABILITY RESULTS.



(c) VARIATION IN SURFACE FINISH

FIG. 3.3. RESULTS OF GRINDING TESTS.

4.0. BALL VALVE ASSESSMENT REPORT

prepared by - G.C. Boshier
G.W.H. Pike

Terms of Reference

To investigate the operation of a ball valve 3 stage sequential switching system. To obtain the repeatability from a given master and also to estimate the production and operating costs for the system.

4.1. Description of System

The ball valve switching circuit (fig. 4.1) incorporates three ball valve units which switch at discrete pressure values. The feedback of pressure to the valves is by means of a conventional measuring unit recording workpiece diameter during the grinding cycle. As the size of the ground specimen decreases, the variation in pressure (fig. 4.3) is fed to an amplifier which gives a magnified signal (fig. 4.4). This signal is fed to the axial connection of the ball valves which act as limit switches. When the input pressure to the ball valve reaches a pre-set value, the ball will "switch" and cause an increase in output pressure. These step increases in pressure are used to control the grinding machine.

Repeatability of the unit is dependent upon the air gauge and ball valve units only. (For a full description of the ball valve unit see ref. 2).

4.2. Repeatability on Test Rig.

Several tests were carried out on the laboratory simulator before it was possible to obtain a consistent series of readings. A fault was found in the electro-pneumatic transducer; to overcome this fault a diaphragm transducer was built in the department.

The simulator test rig with the bread-board version of the ball valve control unit in series is shown in figure 4.2. A series of 100 readings were taken on the first occasion. A statistical analysis of the results obtained have a biased histogram with peaks at each end of the distribution. It was considered that this was due to the fact that a small class interval of 1μ inch was chosen for the analysis, where 1μinch was no greater than the accuracy to which the micrometer thimble of the simulator test rig could be read.

A new series of readings were taken on 22nd November. It was planned to take a total of 100 readings again, but after 76 a sudden discontinuity was noted. This discontinuity was observed to occur when the etching tank began to operate and thus use large quantities of the air. At this point the tests were terminated and 70 readings analysed statistically using a class interval of 5μinches. Results showed a distribution as indicated by the histogram (fig. 4.5).

4.3. Performance on Grinding Machine

The Committee experienced considerable delay before tests could begin on the Studer Grinding Machine. A new wheel, adaptor plates and specimens were ordered; the centres of the machine were reground and the hydraulic infeed actuator was bled. In addition the coolant pump and tray were cleaned and a new coolant specified and installed.

During grinding tests, the unit was installed on the grinding machine three times and tests were carried out as laid down by the Master Programme Committee (ref. 1). Each set of results proved disappointing in that the diameter size was random. After consultation with the Electro-Pneumatic Assessment Committee, who had experienced similar discrepancies in their results, it was concluded that the fault lay in the grinding machine system. To trace, rectify and conduct more tests would extend the project well past the allocated finishing date and, therefore, it was decided to base the comparative analysis on the test carried out on the laboratory grinding cycle simulator.

Figure 4.6. shows the results of the test runs carried out on the Studer grinding machine; it can be seen that there are unaccountable discrepancies which do not occur when the unit is used on the modified laboratory simulator.

4.4. Economics

It was agreed that an important part of the assessment of three switching units would be the overall cost of manufacture and assembly. The one-off cost breakdown of the ball valve unit is as follows :-

	£.	s.	d.
3 ball valves @ 5/-		15.	0.
2 pressure regulators @ £10	20.	0.	0.
1 (12:1) pneumatic amplifier	10.	4.	0.
3 airflow regulators @ £1.15.-.	5.	5.	0.
1 Horizontal edge-wise pressure gauge	6.	5.	0.
1 air filter	6.	0.	0.
Pipe and pipe fittings	2.	10.	0.
Box unit	2.	0.	0.
	52.	19.	0.
i.e. approx.	53.	0.	0.
Contingency 10 per cent	5.	0.	0.
Total	58.	0.	0.

This figure does not cover development costs and overheads which would be necessary to assess if the unit were to be made on a production basis.

4.5. Conclusions

From the repeatability tests carried out, it can be seen that a ball valve unit of the type described can switch accurately to within + 20 in/-10 in.

REFERENCES

4.1. MASTER PROGRAMME MEMO, Recommended procedure for grinding of specimens and for their measurement. Issued 28th October, 1966.

4.2. C.J. CHARNLEY and R.E. BIDGOOD The application of fluid switching devices to the control of a grinding machine.

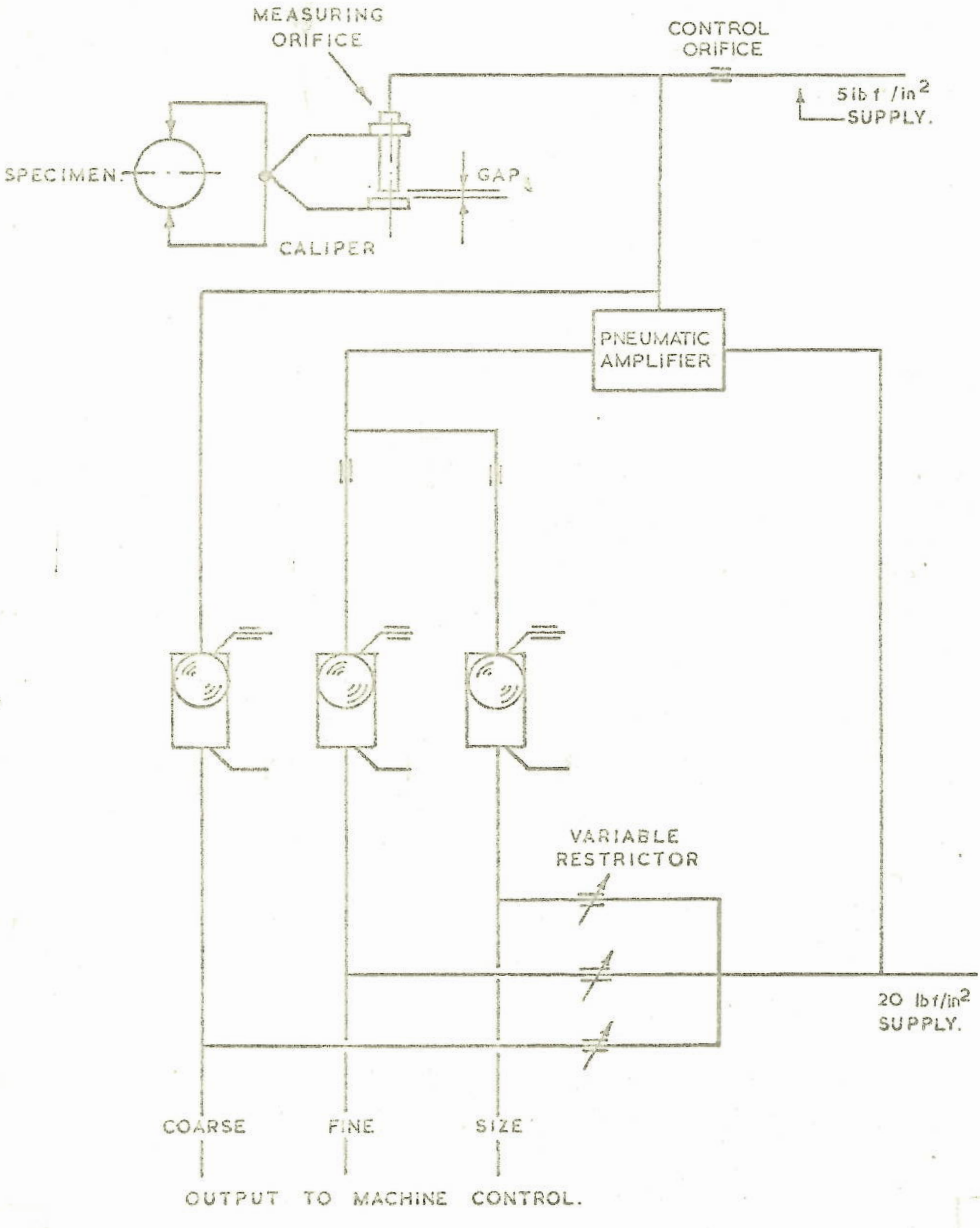


FIG 4.1. FINAL SWITCHING CIRCUIT

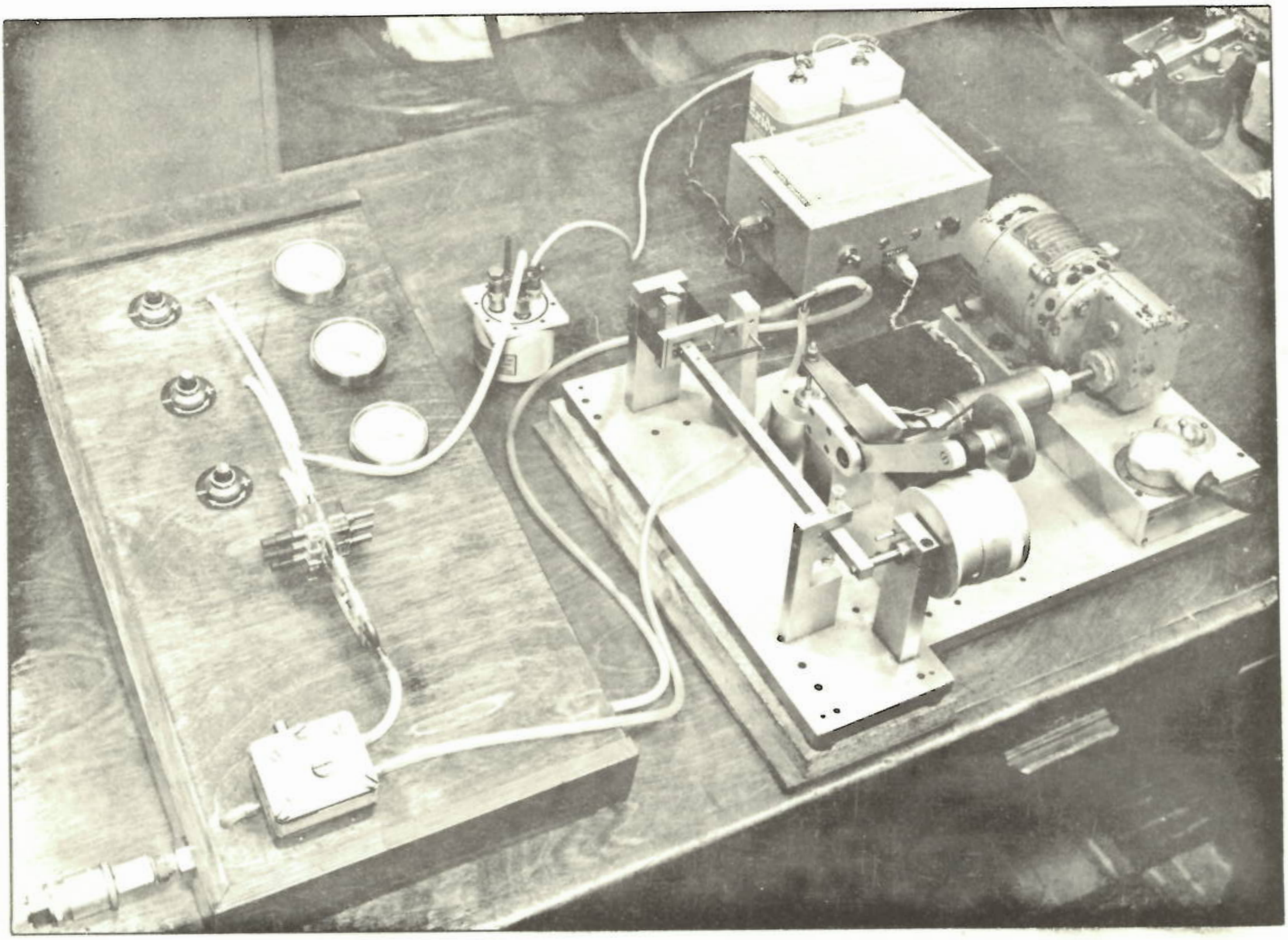


FIG. 4.2. - Ball valve control unit (breadboard version) connected to grinding cycle simulator. The electro-pneumatic transducer was later replaced by a diaphragm transducer.

9C

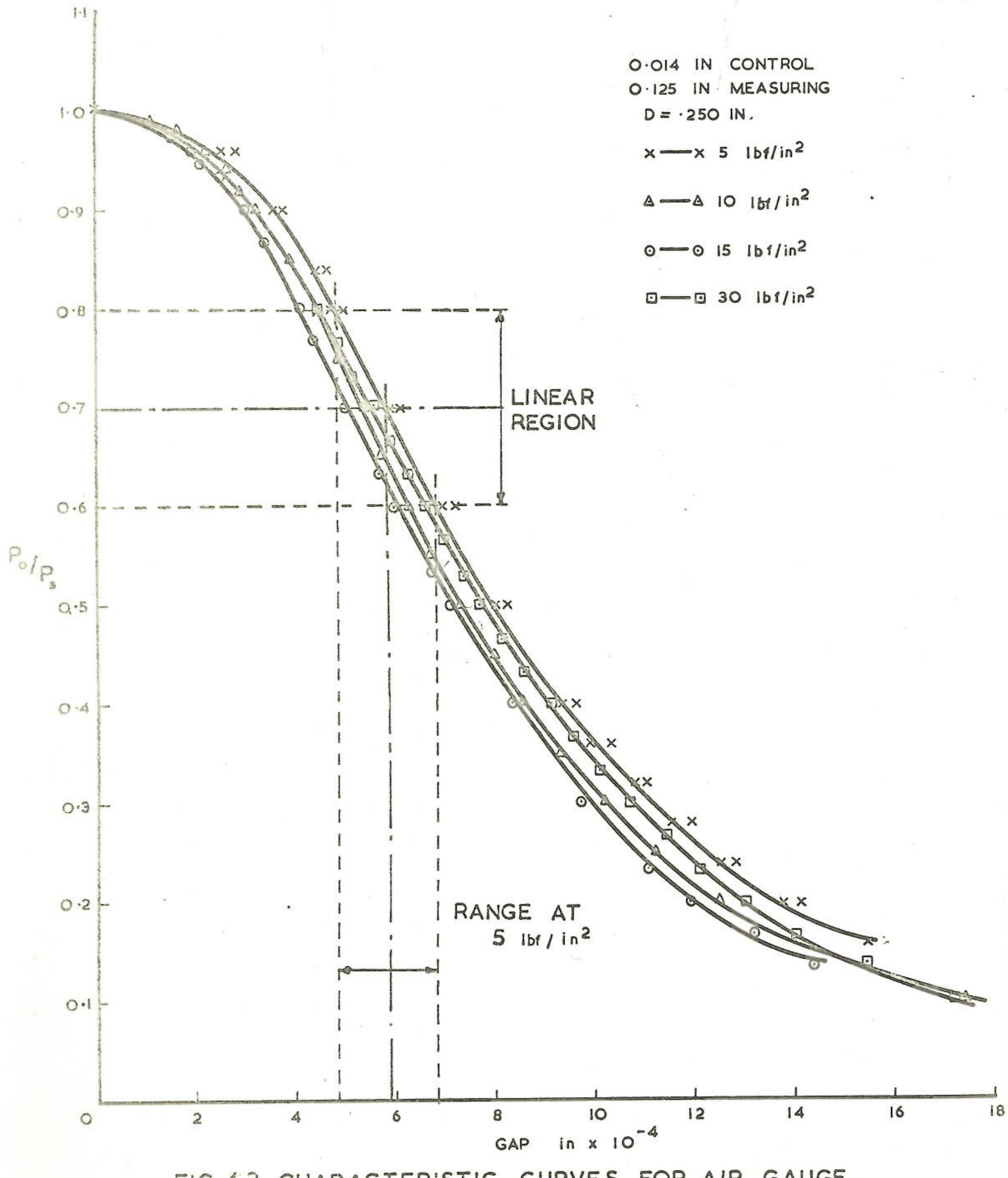


FIG. 4.3. CHARACTERISTIC CURVES FOR AIR GAUGE.

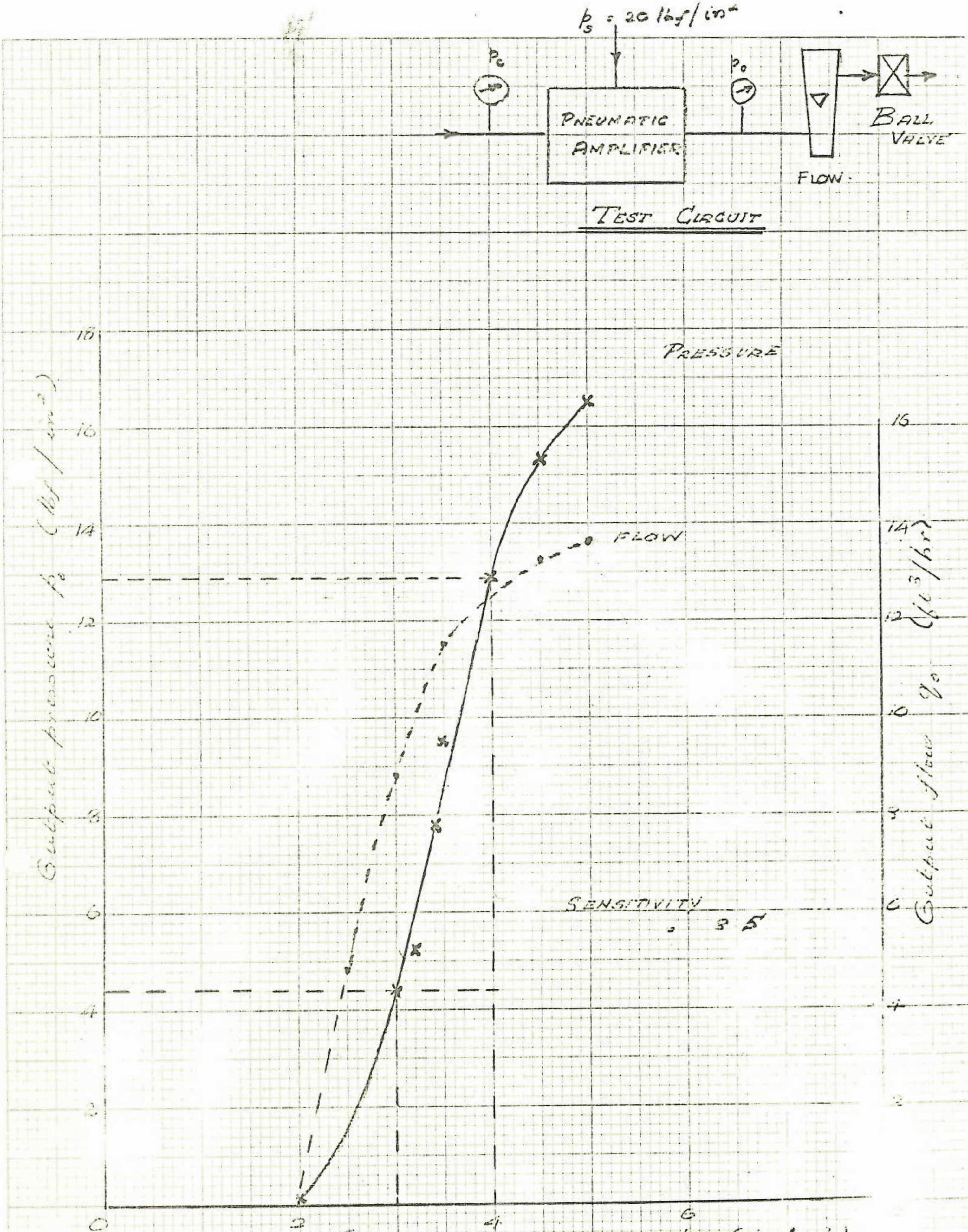


FIG 4.4. Characteristic Curves for Pneumatic amplifier

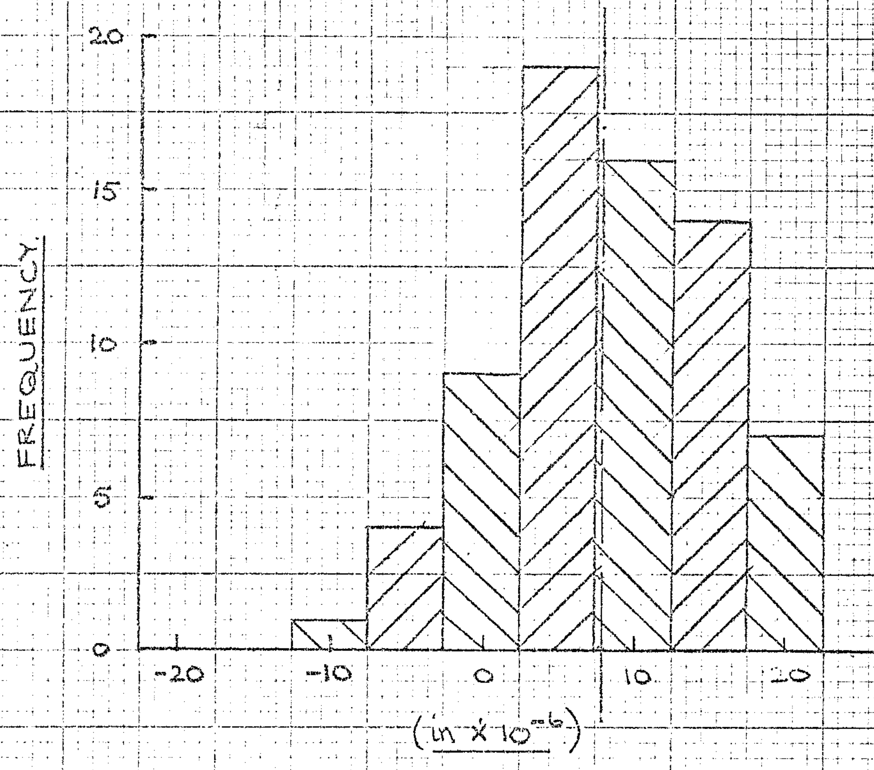


FIG. 4.5. HISTOGRAM OF REPEATABILITY RESULTS.

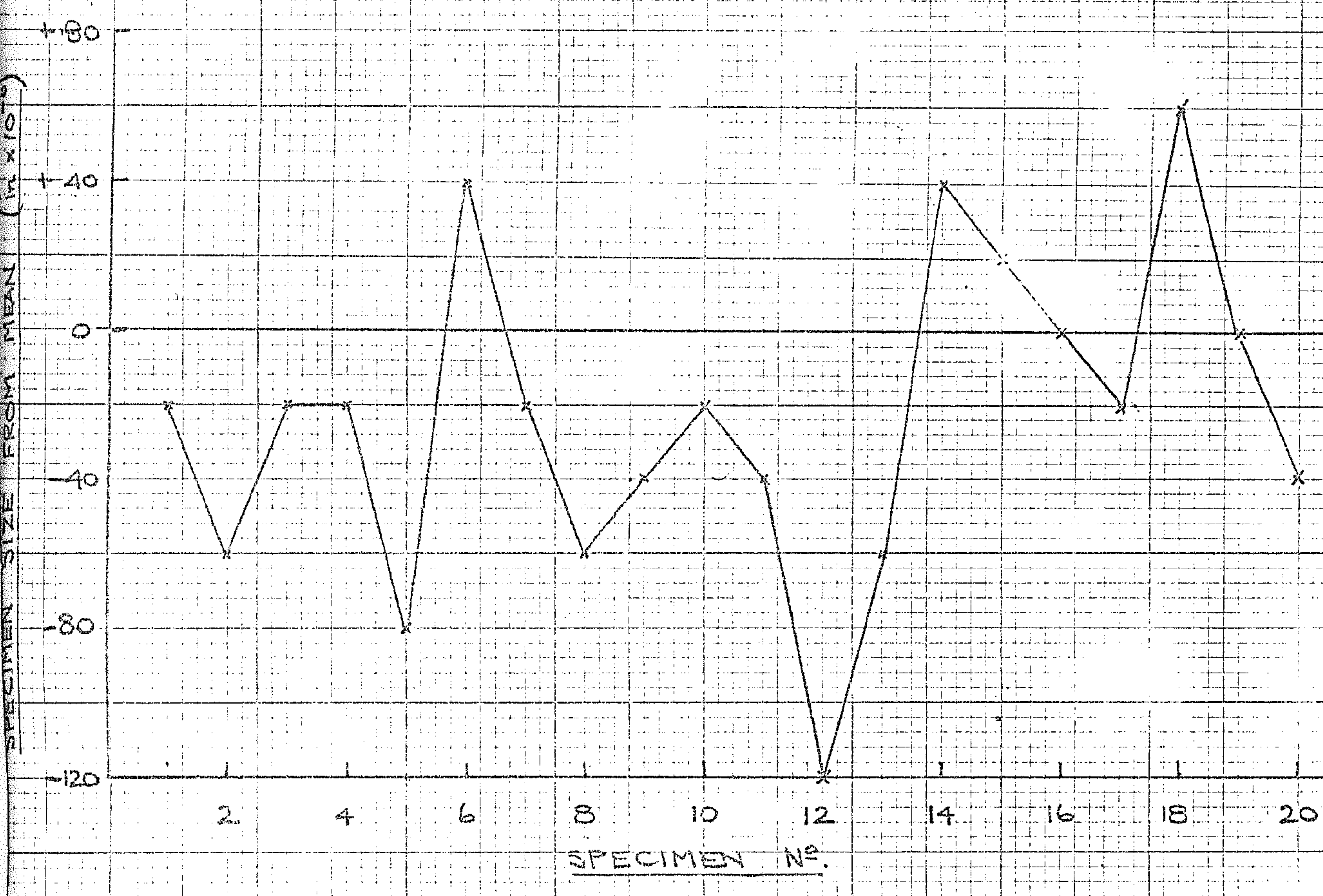


FIG. 4.6. REPEATABILITY OF BALL VALVE UNIT ON THE GRINDING MACHINE.

5.0. PURE FLUID SYSTEM ASSESSMENT REPORT

prepared by - W. Morrison
E.A. Powell

Terms of Reference

To investigate the operation of a pure fluid 3 stage sequential switching system. To obtain the repeatability of specimen size from a given master and also to estimate the production and operating costs for the system.

5.1. Description of the circuit

Fig. 5.1. shows the circuit diagram of the pure fluid system. There are two main parts: the air gauge signal amplification and the switches. These two parts are described in detail in appendices 1 & 2. and it is not proposed to describe them here. The grinding allowance was of such a magnitude that the air gauge signal, when amplified, caused too great a change in control pressure to the switches. It was decided to drive the 'coarse' switch directly from the air gauge, leaving the more sensitive signals from the amplifier to drive the 'fine' and 'size' switches. Corning pneumatic to electric switches were attached to the output of the fluid switches to convert the signals to a form suitable for use with the test rig and the Studer grinder. Because the switches were slightly load sensitive, a small amount of air was allowed to vent through a fixed restrictor. The pure fluid switches were connected to the Studer grinding machine through its existing electro-mechanical relays. However, these were connected such that for normal operation, the 'coarse' relay switched off at the same time as the 'fine' relay switched on. To achieve this from the pure fluid devices, some additional switches were necessary; these are enclosed in the dotted box in fig. 5.1.

As it is shown, two supply pressure regulators are required. One, at low pressure, serves the biases to both the amplifier and the switches; the other is the higher pressure supply to the amplifier, air gauge and the switches. Because of compressor pressure fluctuations, and also the sensitivity of the relative switching positions as a function of bias pressure, both regulators have a common supply from a third regulator which is connected to the 160 lbf/in^2 supply main.

Fig. 5.2. is a photograph of the finished breadboard circuit attached to the grinding cycle simulator.

The air gauge calibration curve is given in fig. 5.3. Clearly the most sensitive measuring gap is when the slope is greatest, and this part of the curve should coincide with the spark out switch point.

5.2. Repeatability on Test Rig

100 readings were taken and analysed. Fig. 5.4. is a histogram compiled from the readings. Because the micrometer could only be read to within half of a small division (5×10^{-6}in) it is not practical to calculate the standard deviation from the mean. However, it can be stated that all the measurements are within a bandwidth of 15×10^{-6}in. This bandwidth might be due in some way to the switching unit characteristics. The switching units themselves are somewhat load sensitive and their switching action was not very sharp.

It was noticed that a second batch of 100 readings taken sometime later had a different mean; while the readings for a single batch were being taken, there was a tendency for the mean to drift, as illustrated in fig. 5.5. Factors which may cause this are thought to be changes in air temperature or changes in humidity causing the Dycril to swell slightly and affect the geometry.

5.3. Performance on Grinding Machine

Several specimens were ground on the Studer grinding machine and their diameters checked in accordance with Master Programme Committee recommendations. These results are shown in fig. 5.4. In view of the results on the test rig and also of the results of grinding tests by other committees, it was concluded that the Studer machine required careful attention before any useful results could be obtained. This has also precluded any conclusive statement as to the reliability of pure fluid control systems.

5.4. Economics

The basic pure fluid system is made up of various units which may be readily made or obtained. The one off cost breakdown is as follows :-

3 'NOR' gates @ £3	£9
2 stage amplifier	6
3 variable restrictors @ £2	6
3 pressure regulators @ £13	39
3 pneumatic-electric switches @ £10	30
Tubing	1
	91
Contingency 10 per cent	9
total	100

A factor covering development costs would have to be added to any production costs, but this might be offset by bulk buying of various items.

Running costs are estimated from the air consumption of the breakdown circuit, which is 57 ft^3/hr at 9.8 lbf/in^2 for the main supply; and 7 ft^3/hr at 2.15in Hg (1.055 lbf/in^2) for the bias supplies. At an estimated 0.2 conversion factor from electric power to air power through the compressor and an electric energy cost of 6d/KWhr the running cost is evaluated at 1d/hr. This cost is low and could reasonably be expected to be reduced with future development of fluidic units having lower air consumption and improved performance.

5.5. Conclusions

It has been demonstrated that a pure fluid sequential control system is feasible, and that the switching accuracy is within 15×10^{-6}in of set size. The characteristics of the units used in the feasibility study were not entirely satisfactory, but this problem is thought to be not too difficult to overcome.

The cost of producing the control system has been estimated at £100, the running cost should be about 1d per hour.

The system is, of course, designed around the Studer grinding machine. The air gauge, amplifier and switches will probably be similar in the way the pneumatic signal is used, with a consequential difference in cost.

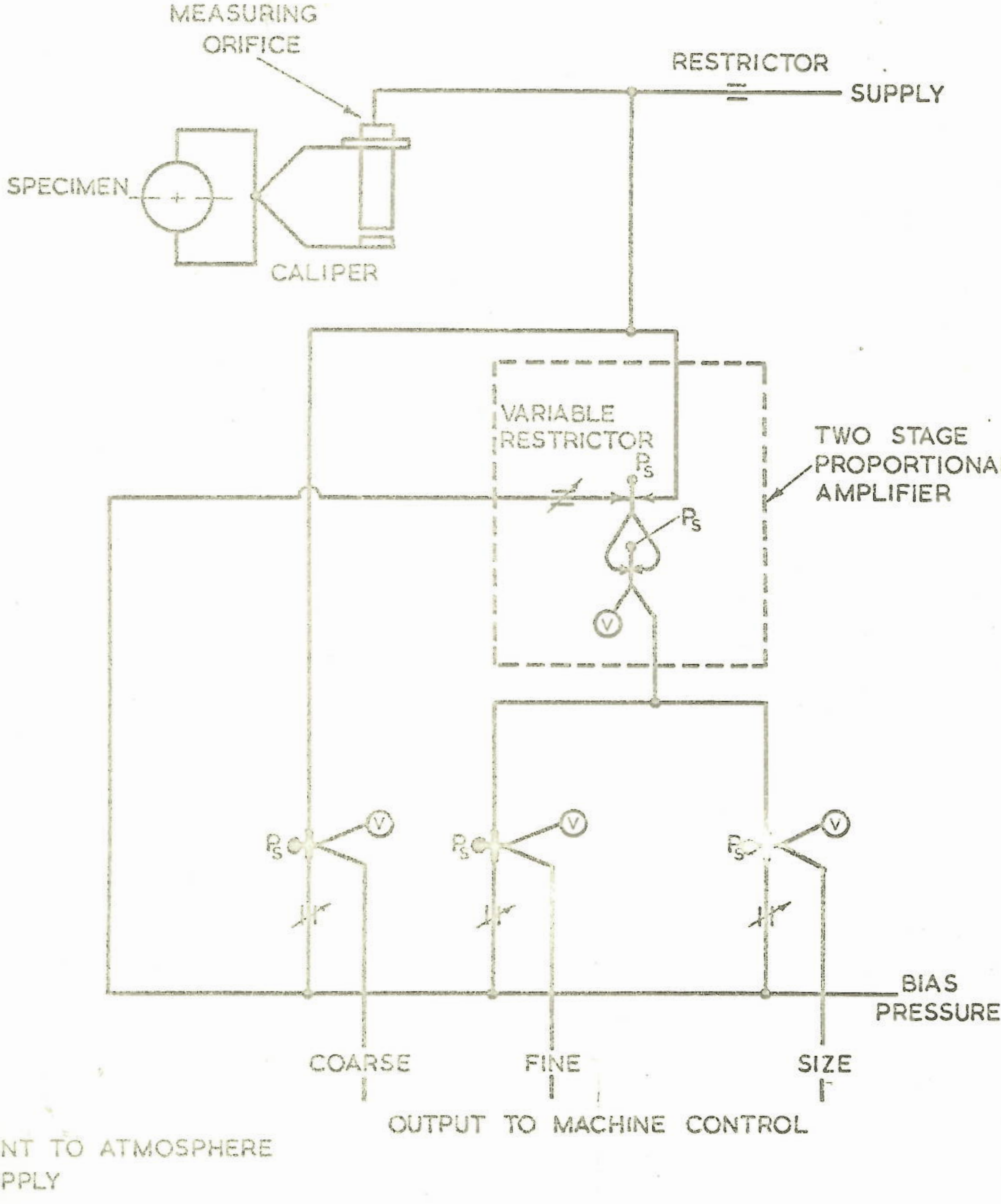


FIG 5.1 FLUIDIC GRINDING CONTROL UNIT.

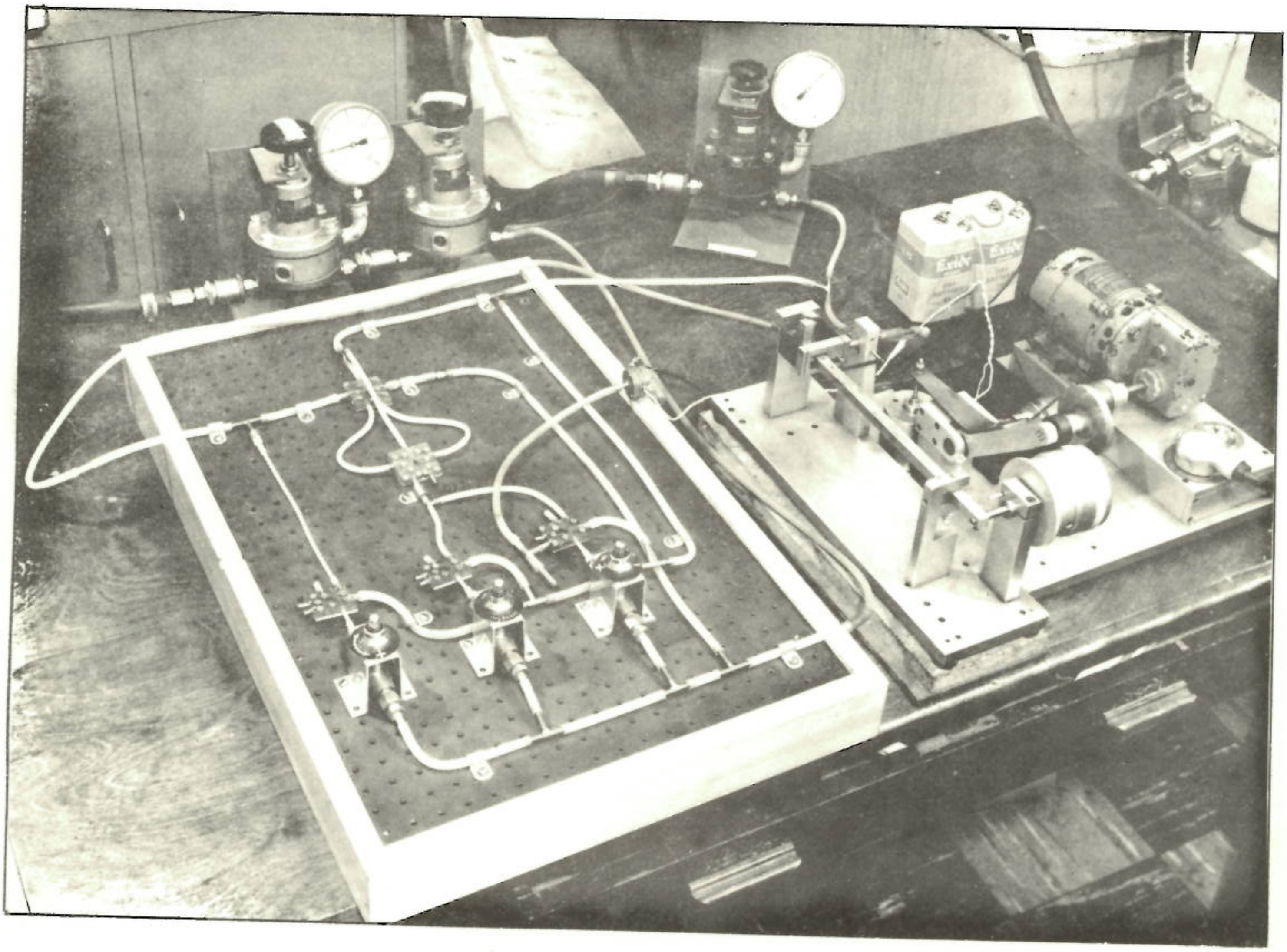


FIG. 5.2. - Wall attachment control unit connected to grinding cycle simulator. The final stage output operates the pneumo-electric switch shown at the top right of the breadboard.

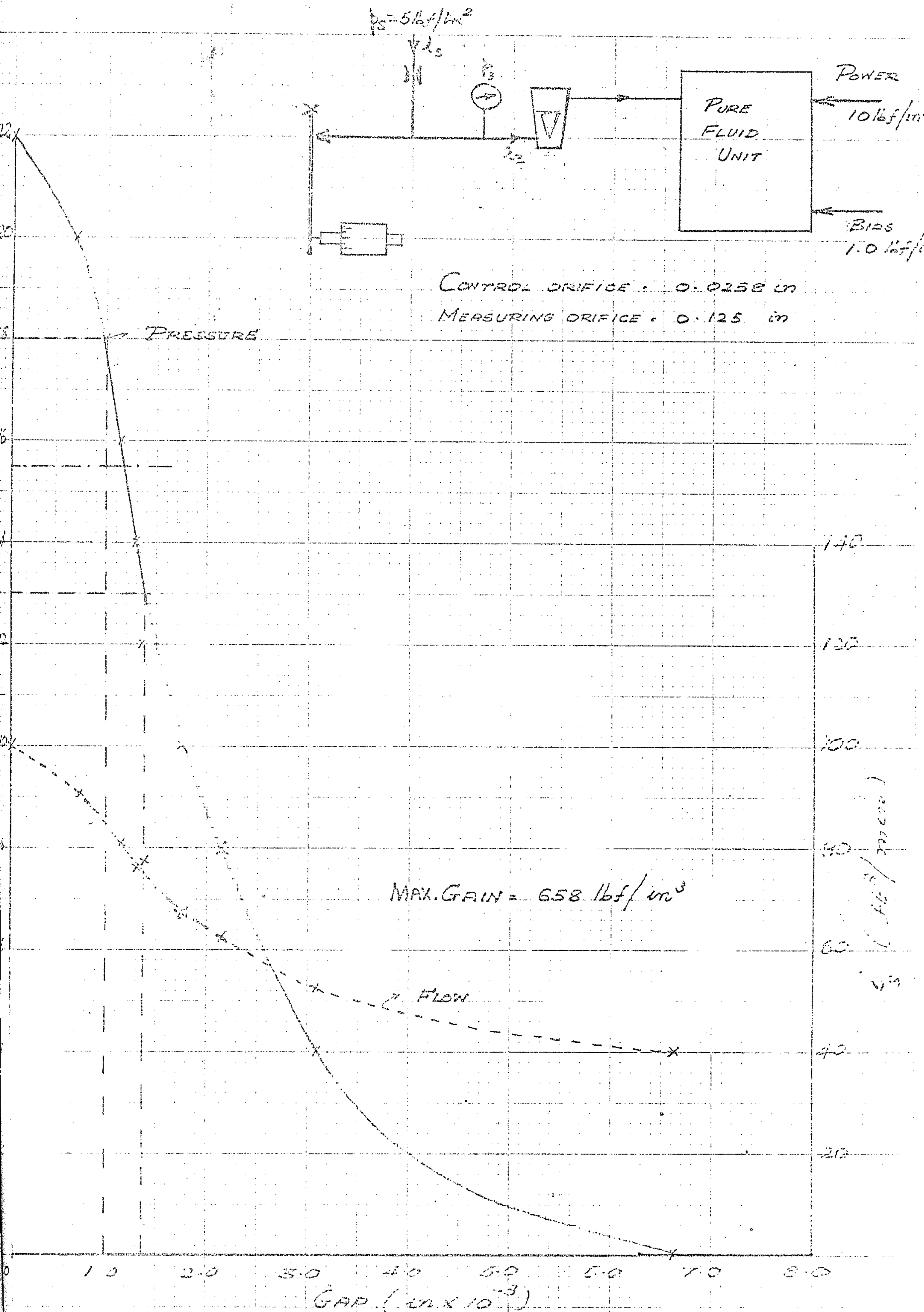


FIG 5.3. AIR GAUGE CHARACTERISTIC

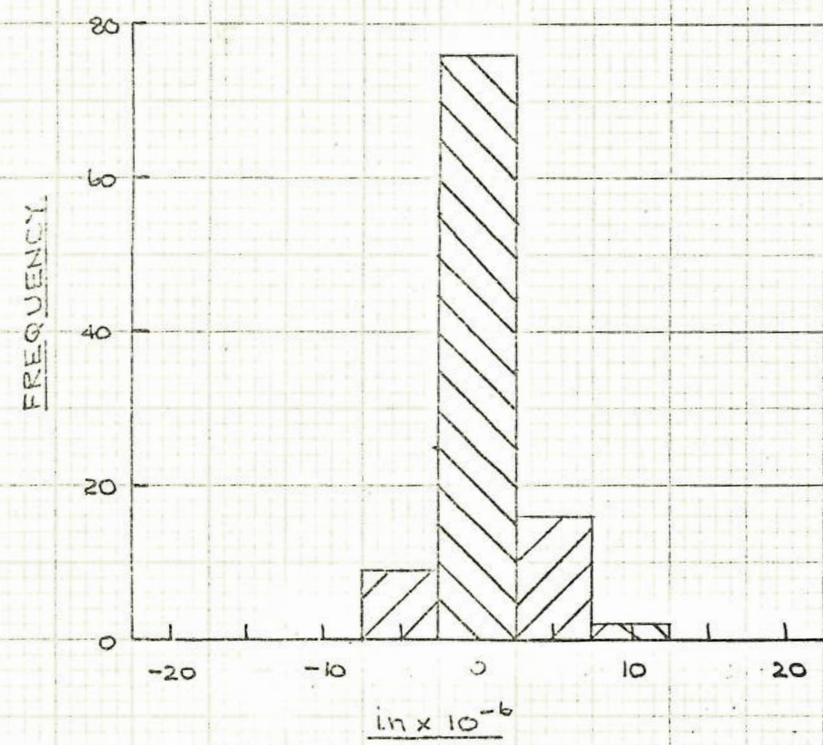


FIG. 5.4. HISTOGRAM OF REPEATABILITY RESULTS.

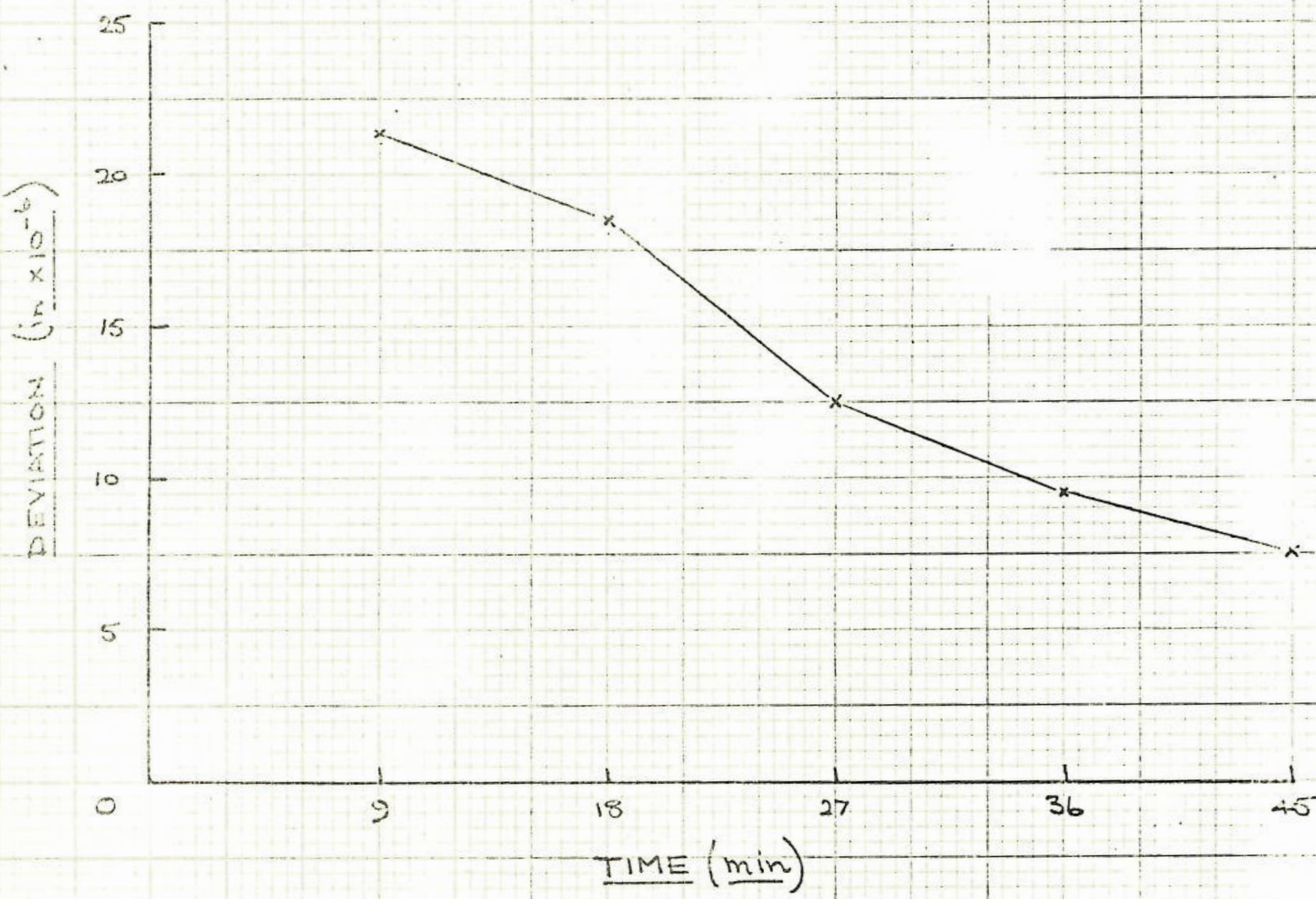


FIG 5.5. DRIFT OF MEAN VALUE.

APPENDIX 1

6.0. DESIGN OF FLUIDIC AMPLIFIER

prepared by - R. Veazey
E.A. Powell

Terms of Reference

To design and evaluate a proportional fluidic amplifier having pressure and flow gains in the order of five when connected to a load of three NOR-units; the gain should occur at an output pressure of between 0 and 5 lbf/in^2 (gauge).

6.1. Initial Investigation

Two configurations of pure fluid amplifier are in general use, the vortex amplifier and the beam deflection amplifier. As little work had been carried out within the College on vortex amplifiers, and the 'button-type' construction requiring precision machining is needed for a high gain amplifier, attention has been focused on the beam deflection amplifier. The latter can be manufactured within the department, and minor modifications effected with relative ease.

Two commercially produced 'Corning' proportional amplifiers, with two-dimensional and three-dimensional vents respectively, were tested to evaluate pressure recovery and pressure gain. Neither unit was found to provide sufficient pressure gain to meet the requirements of a pressure gain of five when connected to the load of the control ports of three wall-attachment devices. As the pressure recovery from the unit with two-dimensional venting was greater, the decision was taken to develop a 2-stage amplifier with this form of venting.

6.2. Development of Design

Design 1. (fig. 6.1a)

Examination of the literature (ref. 1) led to the adoption of a receiver width of 1.5 times the power nozzle width, at a distance of 10 nozzle lengths downstream. This configuration gives a claimed 50% pressure recovery at the expense of low flow recovery. By increasing the receiver distance sensitivity is increased at the expense of output energy.

A power nozzle width of 0.012 inches was adopted for the initial design, and a control nozzle width of 0.018 inches made the unit momentum controlled. A set-back of 0.012 inches was chosen and the control nozzles were of the side entry type, to give the slightly enhanced gain that this arrangement has over the top-entry type. The splitter angle was drawn up to be as acute as is possible to give the highest possible sensitivity.

The unit was etched in Dycril, but the time required to etch out the power nozzle resulted in an increase in receiver distance beyond that of the design. On test, the pressure in both receivers reduced with increasing control pressure, and the unit acted as a low-gain turn-down device, unsuitable for staging.

Design II (fig. 6.1b)

Design I was modified by increasing the splitter angle in order to ensure correct etching. The vents were increased slightly, and three units were etched; considerable difficulty was encountered in etching out the supply nozzles.

The gain of the first unit tested was found to increase with increasing control pressure differential having a maximum value of 5 when driving 3 NOR gates. The linear relationship between output pressure and control differential pressure occurred in the region of maximum output pressure and was limited to 20% of the full range. Subsequent units had gains of four, over a wider range of proportionality.

In view of these results, the decision was taken to build a two-stage amplifier having the geometry of design II.

Design III (fig. 6.1c)

A two stage amplifier was drawn up, with the second stage power nozzle width increased to 0.020 inches and all other second-stage dimensions scaled up in the ratio of 0.020 to 0.012.

In order to improve etching, the length-to-width ratio of the power nozzle was reduced from ten (design II) to zero, thus giving a converging nozzle.

The unit was etched without trouble from the supply nozzle but, unfortunately, when the amplifier was tested, the acoustic noise level was too high for the unit to be incorporated in a production grinding machine.

The pressure gain from the unit had a maximum value of two, whilst driving the three NOR-units. This value of pressure gain occurred at an output pressure of 3 lbf/in^2, rendering the unit unacceptable.

On consideration, it was decided that the noise and poor performance were due partly to the reduction in power nozzle length. C.M. Carne (ref. 3) suggests that an ideal length to width ratio is two. Reduction of this ratio results in increased noise level, and adoption of the configuration of design III results in a 30% drop in pressure recovery. Too long a throat length can give rise to excessive turbulence and an unstable jet, which could explain the variations in performance of the design II amplifiers, instability of the jet making them sensitive to small variations in geometry.

Design IV (fig. 6.1d)

In order to improve on the performance of amplifiers II and III, a new design was conceived. A centre dump was included between the two receiver ports and vented to atmosphere.

This arrangement was adopted in an attempt to obviate the defect in the previous designs of the optimum gain occurring at too high an output pressure. In the simple two-receiver configuration, small geometric variations in the splitter caused the stream to direct itself into one or other of the receiver ports at zero control pressure. This effect is lessened considerably by using a centre-dump configuration, and better repeatability of performance is assured.

Carne's work (ref. 3) suggests, contrary to previous results, that the optimum receiver to power nozzle ratio is 2.0 for an optimum pressure recovery; a power nozzle to length ratio of 2.0 was also adopted.

In order to increase pressure sensitivity, the width of the control nozzles was increased to 2.5 times power nozzle width, and setback reduced to 0.5 nozzle width. The venting arrangement was altered by extending the vents out to the edge of the unit, thereby, it was hoped, reducing the noise level.

Two units were etched with power nozzles, 0.012 inches and 0.018 inches wide respectively.

The two units were double staged and tested with a single supply pressure to the power nozzles of both units. The second stage output was taken to the 3 NOR-unit load, and tests were carried out for 3 differing bias pressures at varying supply pressures.

6.3. Test Results

Figures 8.2 and 8.3 present the results of the test. The maximum pressure gain of the unit is approximately 17, but falls off to 10 at zero output pressure. Maximum flow gains of 16 were obtained over the same range of control pressures as those giving maximum pressure gain.

Reduction in supply pressure reduces the maximum output pressure without changing the shape of the curves, or altering the control pressure range over which maximum gain is obtained.

Increase in bias pressure effectively shifts the output pressure axis to the left. Thus, an increase in bias increases the minimum control pressure which will give an output pressure, without altering flow or pressure gain.

The bias has a similar effect on the flow gain characteristics.

6.4. Conclusions

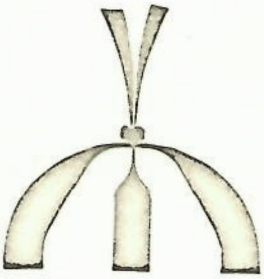
The amplifier design IV produced the required characteristics for the application under consideration, and was therefore passed to the Pure Fluid Assessment Committee.

REFERENCES

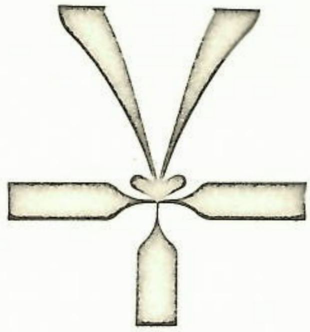
1. Tilburg & Cochran - "Development of Proportional Fluid Amplifiers" 1964.

2. Tilburg & Cochran - "Staging Pressure Proportional Amplifiers" H.D.L. Symposium 1964.

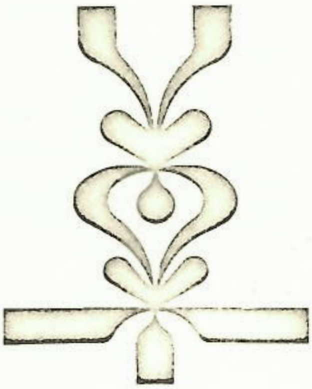
3. C.M. Carne - "Experiments in the Momentum Interation Principle to Produce a Proportional Fluid Amplfier". 2nd Cranfield Fluidics Conference 1967.



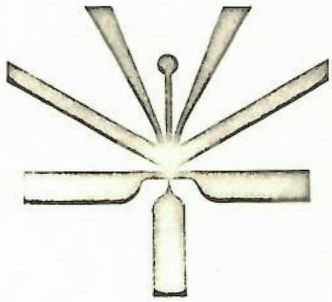
a) DESIGN .1.



b) DESIGN .2.



c) DESIGN .3.-2 STAGE



d) DESIGN .4.

FIG.6.1. PROPORTIONAL AMPLIFIER SILHOUTTES.

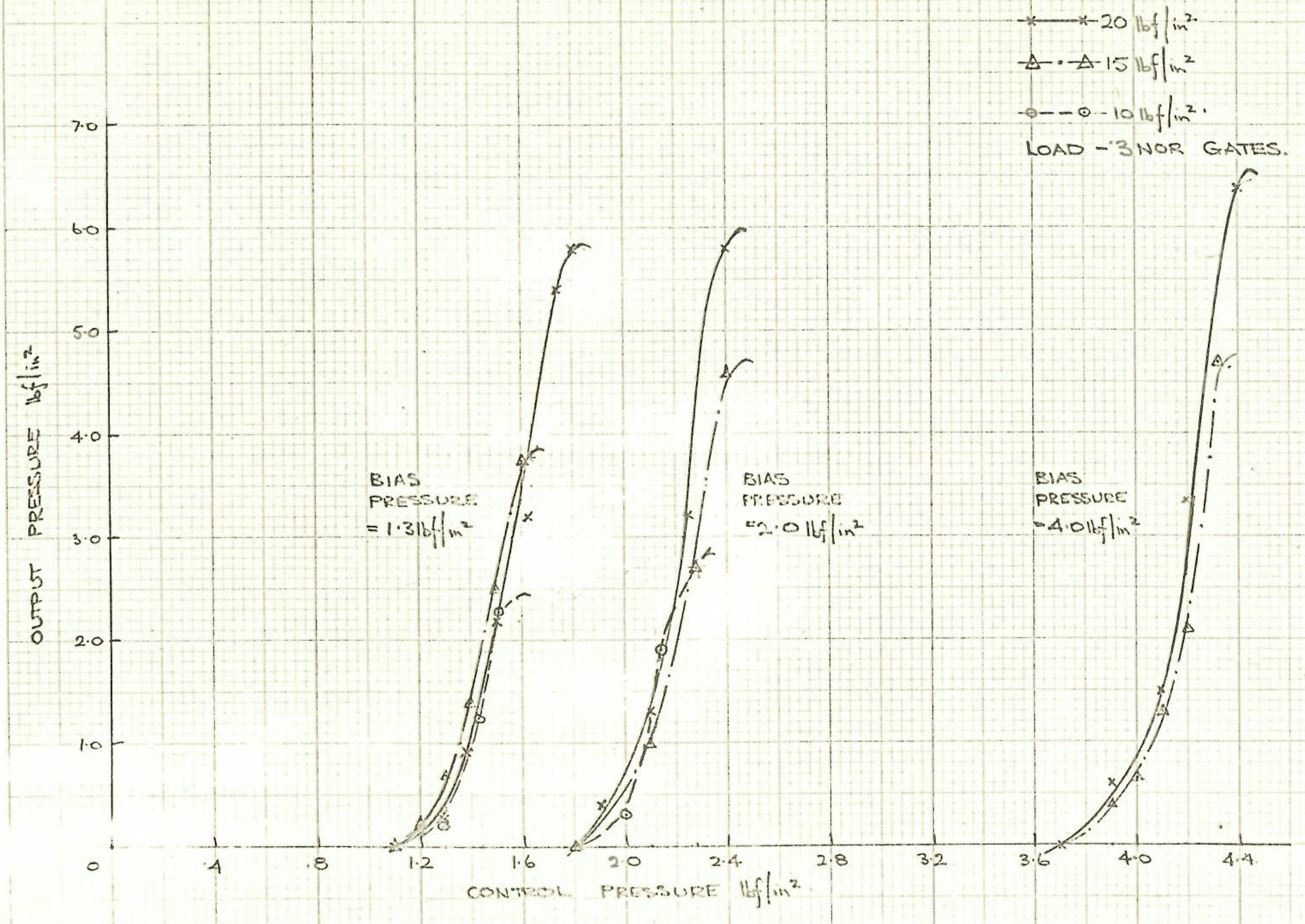


FIG 6.2. PRESSURE CHARACTERISTICS

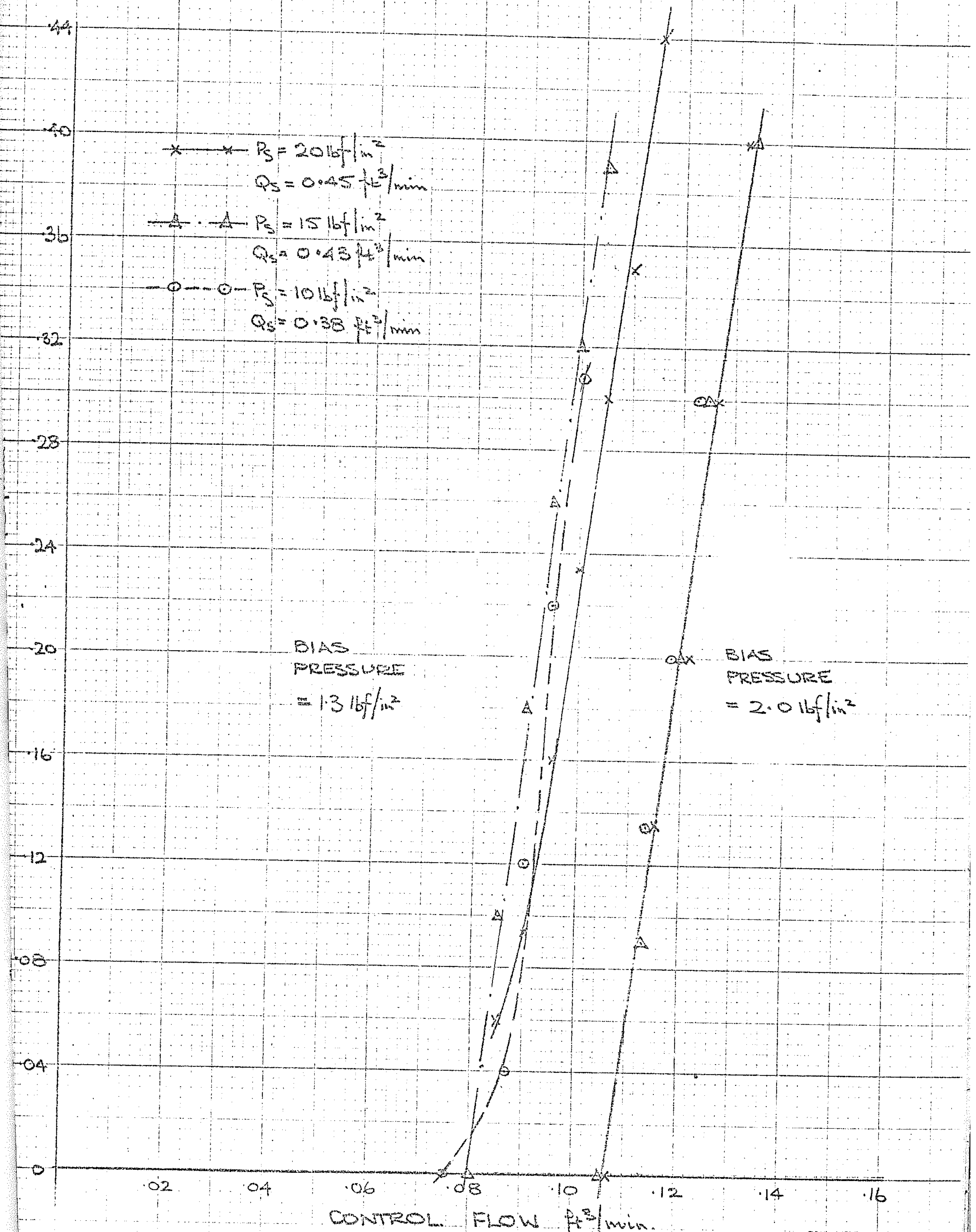


FIG 6.3. FLOW CHARACTERISTICS.

APPENDIX II

7.0. DESIGN OF 3 STAGE FLUIDIC SWITCH

prepared by : G.W.H. Pike (Chairman)
G.C. Boshier
W. Morrison
R.S. Sutcliffe

Terms of Reference

To develop a system of pure fluid wall attachment devices to initiate the coarse and fine feeds, and the stop/withdraw wheel signal of the Studer grinding machine. The units must cope with a fine machining allowance of 2×10^{-4}in and switch with 99.9 per cent confidence within $\pm 30 \times 10^{-6}$in of a preset size.

7.1. Introduction

Recent developments in fluidic devices have led to the present attempt to use these devcies to control the process with at least the same degree of precision as had already been achieved with the electro-pneumatic and ball valve methods.

This report describes an investigation by the Switching Section into the design and development of a pure fluid system to control the grinding cycle.

7.2. Choice of Method

Survey of possible methods

Two of the basic pure fluid switch units (of the wall attachment type) which are currently available are monostable and bistable. In the former the supply is normally attached to one wall of the unit; when a control pressure is applied the stream switches to the other wall, but on removal of the control pressure the stream will return to the original wall. The bistable element is controlled similarly except that the stream will only return to the original wall by the application of a control pulse from the other control channel.

In order to arrange for similar units to switch at higher control pressures, the elements must be biased at higher pressures, and in this manner sequential switching may be achieved. The bias pressures are provided from-a constant pressure supply via variable restrictors as shown in fig. 7.1.

Both monostable and bistable units were considered and tests were carried out on each type to determine which was more suitable for the final design.

Test results

Fig. 7.2 shows the relationship of control pressure with bias pressure. The bistable unit required a greater change in bias pressure for a given control pressure increment. The hysterisis was also mugh higher for the bistable unit, and this was considered undesirable in case the unit did not reset itself during actual operation.

It was decided to carry out repeatability tests using the 3 input OR/NOR gate and, accordingly, the unit was connected up with a fine control valve in the control line. A first set of 100 readings of control pressure to switch the supply to OR were taken. These were found to be affected by the compressor pressure fluctuation as can be seen from fig. 7.3. For the second set of readings, two pressure regulators were connected in series. The second set of readings showed that the unit was capable of switching to within $\pm$ 10 x 10^{-6} in. It was then decided to recommend amplification of the control signal from the air gauge by a factor of 5.

7.4. Conclusions

It was decided to proceed with the use of three biased monostable units coupled together with a common supply and control from the amplifiers.

7.5. Three Switch Unit

Composite Unit

The first attempt was made when some difficulties were still being had with the etching tank. These difficulties are the subject of a separate report for the project. Fig. 7.4 shows the photographic outline of the composite unit. This was set up 3 times full size using single input NOR units (adapted from the original 3 input design).

The first plate so made demonstrated good switching with two of the NOR units, but was proportional on the third. An unsuccessful attempt was made to correct this using surgery. A second plate was etched, but this was also proportional on two of the switches; again surgery failed to correct the fault. Both these units were made using the Coanda nozzles in the etching tank. At this stage the nozzles were replaced by the original hand spray.

A third plate was etched, but this too gave poor results. The photographic negative was examined on the shadowgraph and it was discovered that the regions where two of the three inputs had been cut off were badly formed causing partial blocking of the control channels.

To enable the project to be completed within the time scale, it was decided to postpone the manufacture of a composite plate and make a 'breadboard' version utilizing three ordinary NOR gates.

Breadboard units

Several 3 and 4-input NOR gates were tested to select three units which exhibited sharp switching properties. These were connected together with three variable restrictors on the bias side. It was proved that these units were capable of being switched in sequence.

7.6. Conclusions

Although the composite plate is a potentially simpler and neater way of presenting a methodof sequence switching, time limitations were such that this method could not be successfully concluded. In the meantime three NOR gates were mounted on a breadboard and simple testing demonstrated their capabilities. The switch units are therefore ready for coupling to the amplifier and the grinding cycle simulator test rig for repeatability tests.

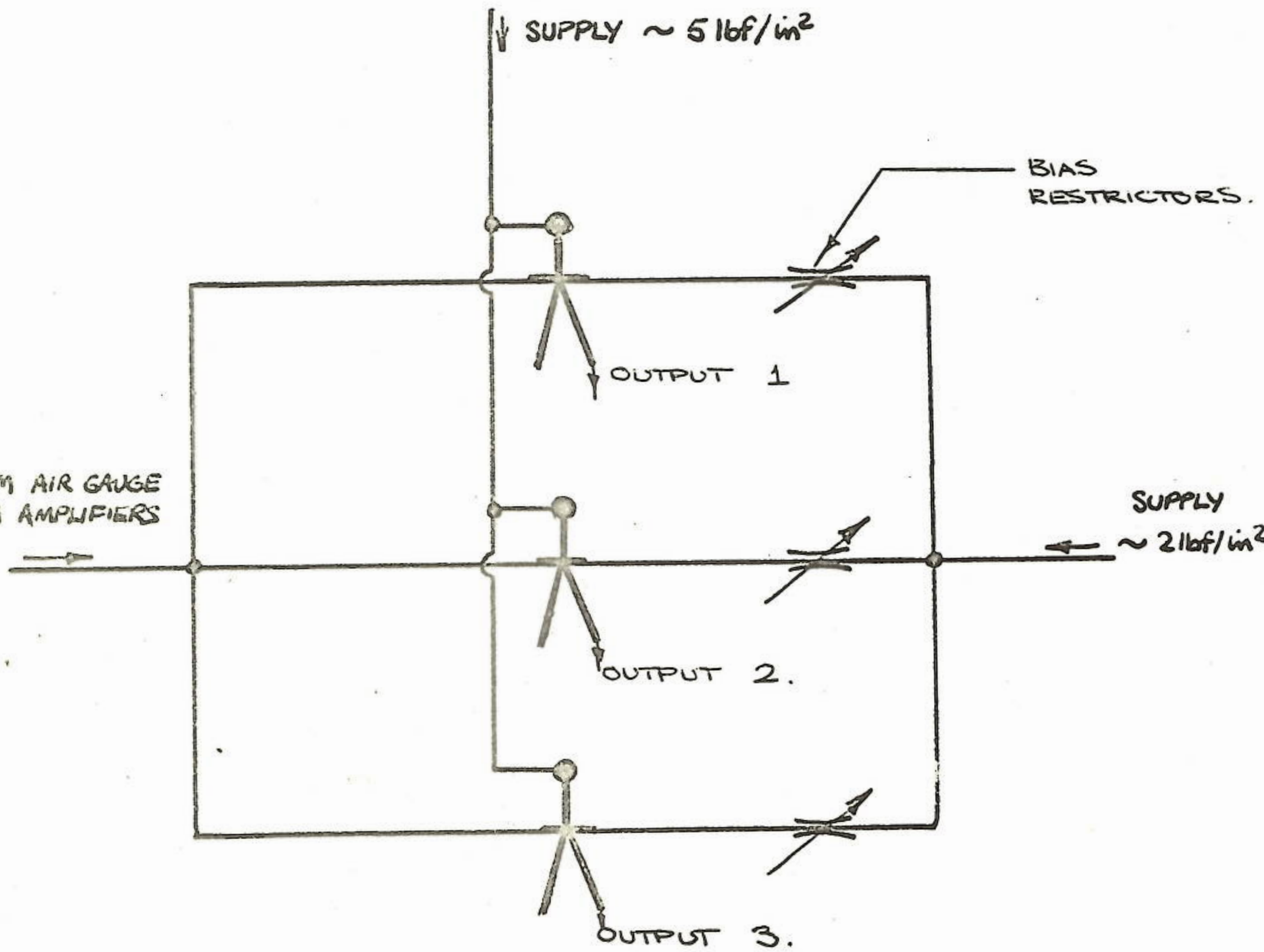


FIG 7.1. SWITCHING CIRCUIT DIAGRAM

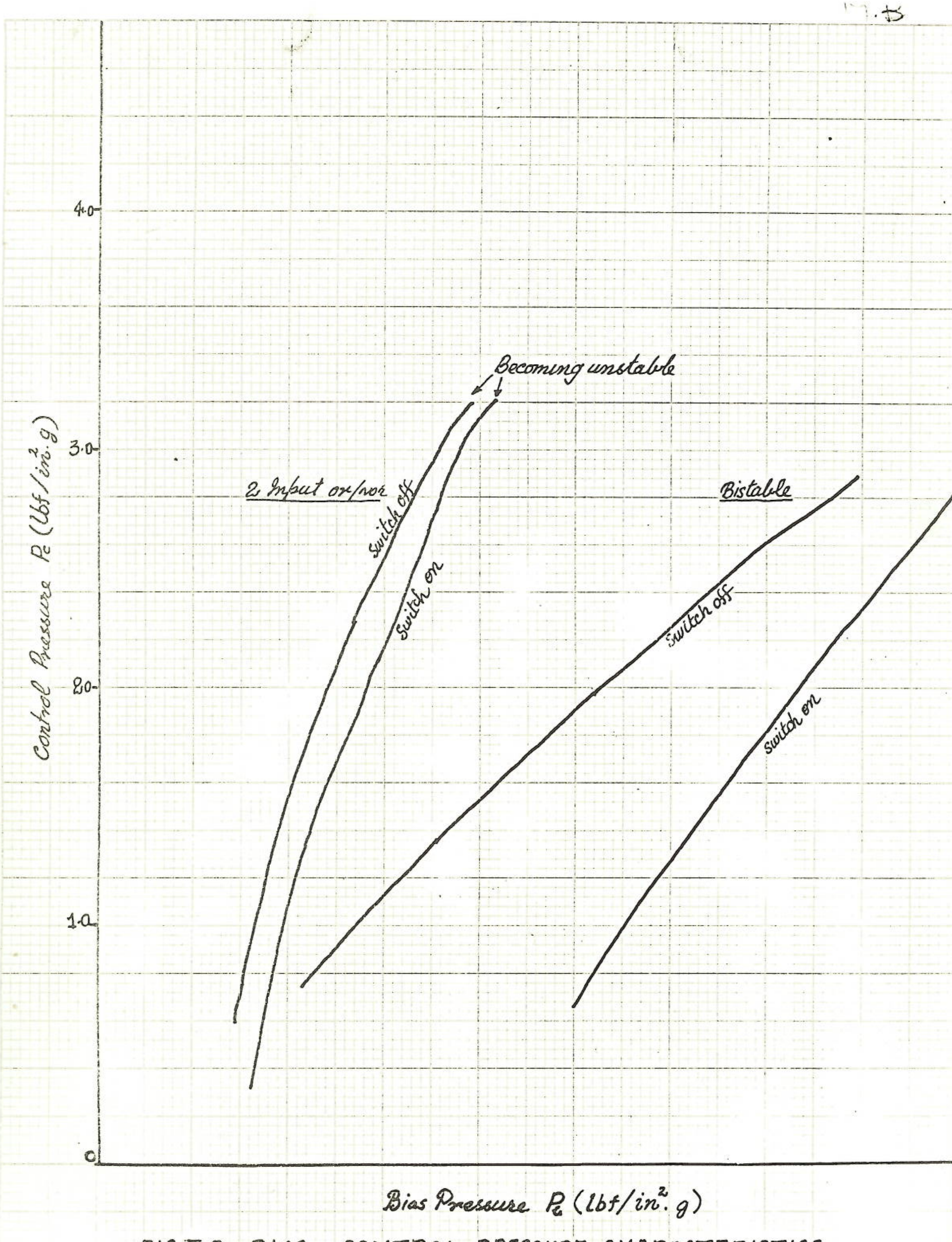


FIG 7·2 BIAS ~ CONTROL PRESSURE CHARACTERISTICS

FIG 7·3 FLUCTUATIONS OF COMPRESSOR PRESSURE

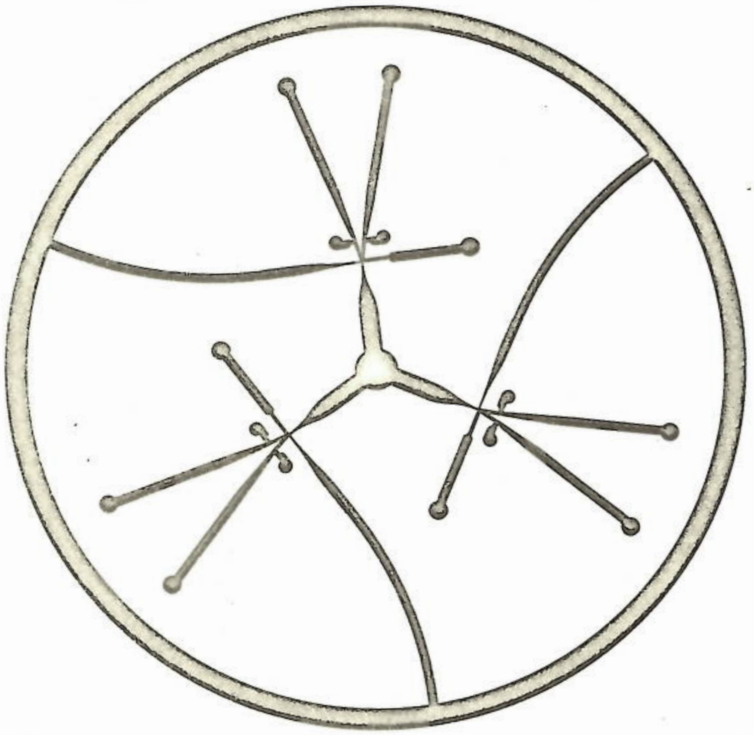


FIG. 7.4 - Photographic outline of composite 3 switch unit. (scale - full size).