INSTRUMENTATION AND CONTROL OF THE CANBERRA HOMOPOLAR GENERATOR BY ON-LINE COMPUTER

EP-RR 11

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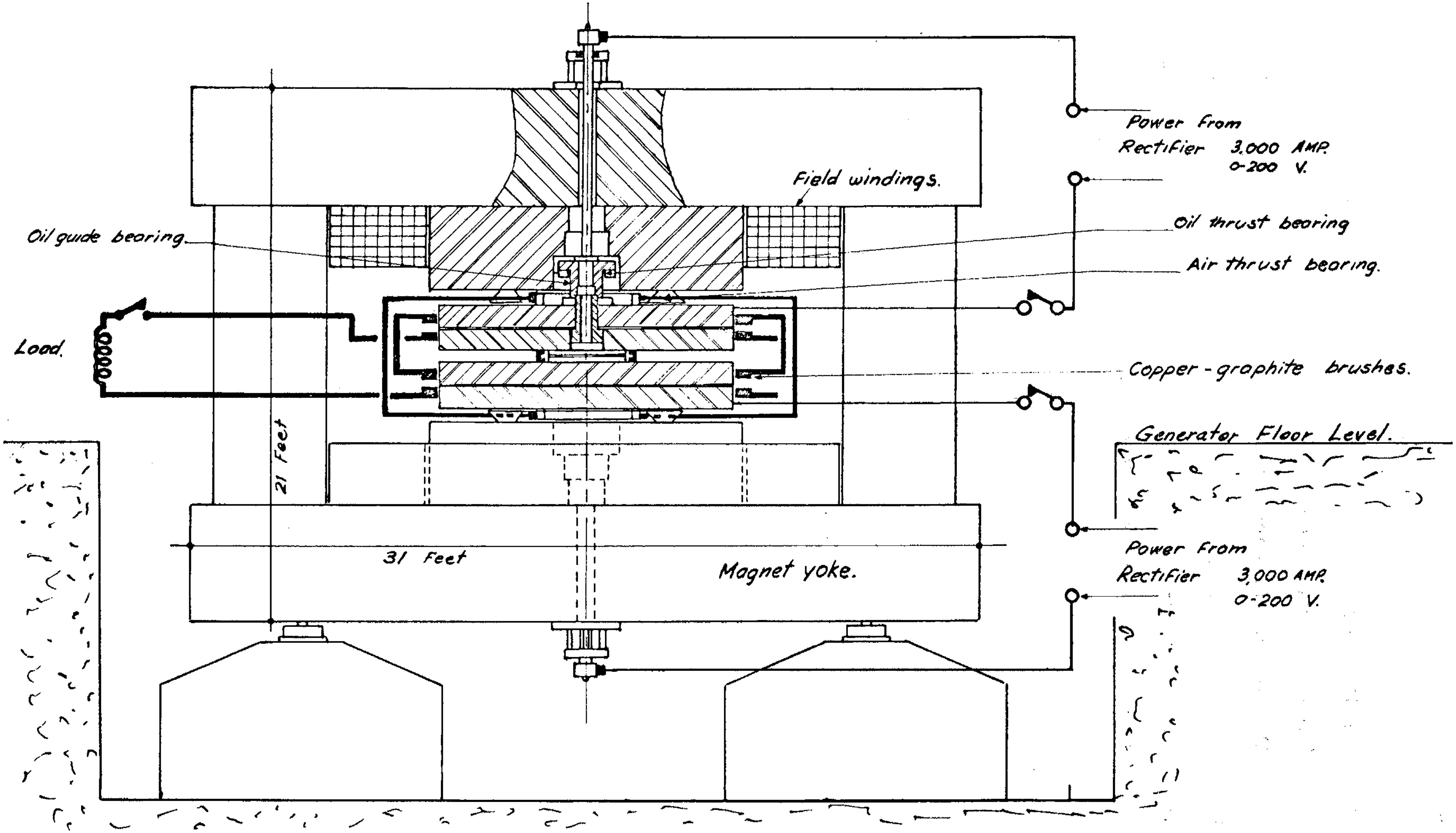

THE A.N.U. HOMOPOLAR GENERATOR is an energy storage device to store 560×10^6 Joules, taken from the Electricity Supply over a period of 15 minutes. The unique feature of the machine is that all this energy can be delivered to the load in one second.

The Maximum Voltage = 900 Volts.
" Current = $1{\cdot}6 \times 10^6$ Amps.
" Power = 1000 Mega Watts.

FIGURE 1.

I. INTRODUCTION

Installed in the Department of Engineering Physics of The Australian National University is a large homopolar generator (H. P. G.). This generator is a suitable source of large amounts of stored energy and has been described in detail elsewhere.[1] It will be outlined only briefly below.

The construction of the H. P. G. is depicted in Figure 1. The rotors are restrained laterally by an oil-filled guide bearing and are pulled against large air bearings (which restrain movement in a vertical plane) by oil-filled guide bearings. After the main field is established (perpendicular to the rotors) by passing current from a motor-generator set through the field windings, the rotors are accelerated from standstill by supplying current from a mercury arc rectifier in a radial direction through the rotors via a "motoring" set of copper-graphite brushes. When the rotors have reached the desired speed, a large amount of rotational energy is stored. This energy is converted back to electrical form by applying the air actuated "pulsing" brushgear and raising the electrolytic bath in the electrolytic switch until the electrodes are immersed. The pulse current duration and shape are controlled by varying the depth to which the electrodes are immersed. To enable insulation levels to be monitored and to reduce the likelihood of a full short-circuit, the live parts of the H. P. G. are normally not grounded.

At present, the H. P. G. is manually controlled from a central control room; the H. P. G. "operator" directing activities with the help of several assistants and extensive instrumentation together with various automatic controls.

Because of the H. P. G.'s complexity and its critical dependence on the correct operation of such auxiliaries as oil and air supplies, some form of overall automatic control system is desirable.

The implementation of the supervisory function of such a system will be simplified by the large amount of data, relating to the normal performance of the H. P. G., which has been collected. Several basic control systems, such as the rotor speed equalising control, have already been developed and are operating satisfactorily. These, in combination with the extensive existing instrumentation, will also be of substantial assistance.

Three possible approaches to the realisation of a suitable control system are:

(a) the construction of a special purpose control system consisting largely of discrete servomechanisms, operational amplifiers and logic circuitry.

(b) the programming of a digital computer to perform the same functions as the discrete circuitry and additional functions which would be impracticable using approach (a).

(c) a combination of the methods of (a) and (b), using those features of each system which are most readily performed by it--the "hybrid" approach.

The extended capabilities and flexibility of the third approach make the "hybrid" solution appear the most promising. The large amount of data logging to be performed during the operation of the H. P. G. and associated experiments, makes the availability of a digital computer desirable and it is a simple matter to process data for control purposes once it has been acquired for logging, assuming that processing time will not be a limitation. Fortunately, a digital computer (an IBM/360 Model 50) and a data control unit (a model 1827), are installed at A. N. U. The data control unit, together with its solid-state multiplexer and analogue to digital (A-D) converter, will be required in the conversion of analogue transducer outputs to digital form and as an "interface"* to the /360 data channel. By means of this interface, the digitized transducer outputs can be transferred to the computing system. Facilities for analogue output have been installed in the 1827 and facilities for digital input and output are available but have not yet been installed. The digital computing system will be referred to as simply /360 ("system 360") and the data control unit as the 1827. The relative ease with which analogue circuits can perform such functions as alarm scanning means that in the overall system they will have many applications.

It is the purpose of this study to examine and assess some methods by which the "hybrid" type of system can be applied to the H. P. G.

2. SYSTEM REQUIREMENTS

Set out below are some general requirements for the proposed system of control and data logging. In section 3, a method of implementation is outlined and examined for compliance with the following requirements.

2.1 Data Logging

Associated with the operation of the H. P. G. and the experiment connected to it (hereafter referred to as the "experiment"), will be a large quantity of data which is to be acquired and recorded. The data will have to be obtained as electrical signals by suitable transducers and then converted to a form acceptable to the computer's 1827 data control unit. Some of the recorded data will be required permanently and will have to be printed out, presented graphically or stored digitally in removeable storage. Other recorded data, particularly that relating to the H. P. G. will normally be required only in the event of unsatisfactory or unusual operation and a summary of main events such as maximum oil temperatures, will usually suffice.

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* The "interface" is a communication link between data channel elements and control units in /360. Information such as data, sense and status information, control signals and I/O device addresses, is transmitted in both directions over the time and function shared signal lines of the interface. All transmissions are interlocked with corresponding response signals, permitting system input and output operations that are not dependent on circuit speeds.

This summary should contain sufficient information to enable the operator to decide whether or not more detailed information will be required. Where practicable, the output data should be well documented, edited and condensed, so that interpretation will be simplified.

2.2 Data Processing

Facilities for performing a wide range of mathematical and logical operations on acquired data will be required. Programs, such as one for determining the H.P.G. configuration and parameters necessary for a given output pulse, should be able to be called, when required, to manipulate data entered by the operator. Some transducer outputs, such as the insulation level monitor, do not bear a linear relationship to the variable (e.g. insulation resistance) being measured and mathematical operations on the sampled values will be required.

2.3 Automatic Control

Automatic control will have to be applied at several levels, ranging up to an overall "supervisory" control. Various control functions may be necessary for different experiments and the control system should be sufficiently powerful and flexible to handle a wide and changing field of control responsibilities.

The supervisory control system should co-ordinate the whole range of normal H.P.G. operations and have the ability to handle malfunctions and emergencies. These supervisory facilities should also be available to the experiment.

2.4 Alarm Scanning

For each of the functions upon which successful operation of the H.P.G. and experiment depends, the limits of satisfactory performance can be estimated for any phase of operation. These estimates depend on past experience as well as on physical considerations (such as the maximum temperature for which the properties of lubricating oil are satisfactory). A "malfunction" is any excursion of a variable outside this range of satisfactory performance, whether actual or indicated. When a variable being monitored is within its limits, an indicated malfunction is a different type of malfunction (this time within the measuring and comparing equipment), and the system should be designed to minimize the occurrence of this type.

All malfunctions must be detected without undue delay and, where possible, verified before taking further action.

2.5 Communication with the Operator

A satisfactory two-way communication link between the computer and the operator must be established. In the initial stages of implementing the control program, the operator could be asked for, and would have to give, approval of any major decisions made by the computer programs. This communication link could also be used for warning messages to the operator and for requests by the operator for particular services.

2.6 Relationship to Other Users of the /360

Consistent with performance requirements of the H.P.G. programs and with the cost of installing special equipment, as little interference as possible should be experienced by other computer users (both on-line and off-line). This comment applies to three domains within the /360 viz:

(a) Central processor time

(b) Main core storage and random access storage

(c) Input/output (I/O) devices common to the H.P.G. program and other users.

2.7 Reliability

During implementation of the control and data logging system, as little change as possible should be made to existing instrumentation and control systems. By the use of this approach, manual control can easily be reinstituted in the event of failures in the automatic system. If possible, the failure of components in the automatic control system should cause reduced service rather than sudden total failure, i.e. it should "fail softly".

A measure of redundancy should be employed in the measuring and preliminary processing of important variables so that some failures in transducers and circuitry could be tolerated.

Because of the possible serious consequences of an accident with the H.P.G., the "fail safe" technique must be applied.

2.8 Phased Implementation

To ensure a smooth transition from manual to automatic control, the data logging and control functions should be capable of being installed in stages, with each stage being "debugged" before proceeding to the next. A suggested phasing is:

(a) Data logging

(b) Operator - /360 communications

(c) Malfunction detection

(d) Data processing

(e) Automatic control - first level (elemental) e.g. rotor speed balancing control
- intermediate level (functional), e.g. "motoring" sequence
- supervisory (overall)

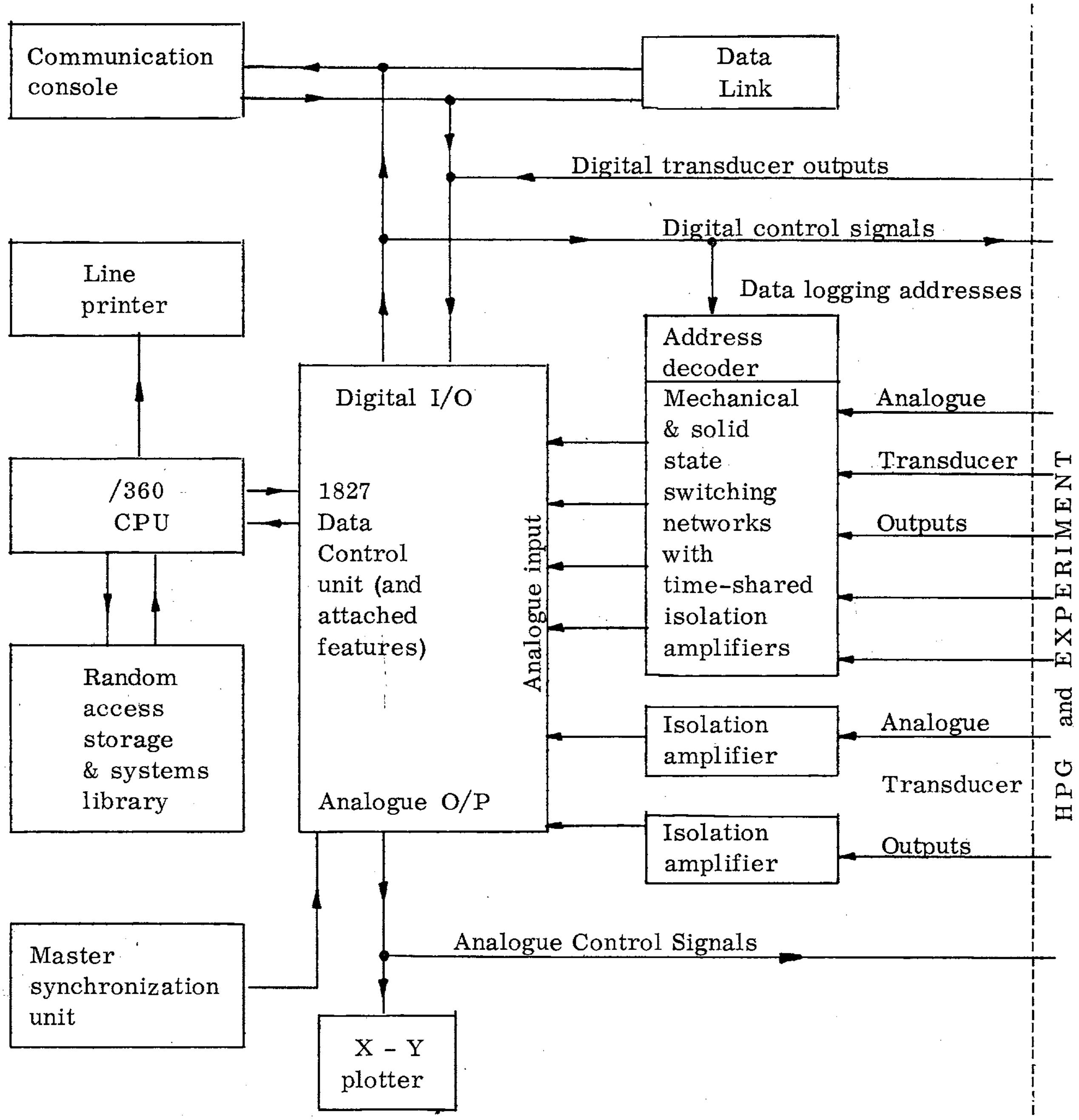

Figure 2. Proposed Physical Implementation

3. PROPOSED METHOD OF IMPLEMENTATION (see Figure 2)

The variables to be logged, alarm scanned and/or controlled for the H. P. G. and the experiment, will be converted into electrical signals by suitable transducers (many of those for the H. P. G. being already installed and operating). These signals will be converted (e. g. by isolation amplifiers) to a form acceptable to the 1827 data control unit which will in turn further translate them into a form acceptable to the /360 data channel. Within the computer's central processing unit (C. P. U.), a small "main line" program, which will always be available, will recognize various requests for service (entered either automatically or by the operator) and call sub-programs resident in the systems library (located on the 2311 disk drives) into the main core storage of the C. P. U. These sub-programs will be designed to handle specific requests such as data logging and malfunction handling.

The computer will communicate with the operator via the communication console, and with the various controllers at its command via the digital and analogue output features of the 1827.

Data which has been acquired and is to be logged, will be stored on one of the computing system's 2311 disk drives until required, when it will be outputted on the system's line printer, an X - Y plotter connected to the 1827 analogue output, or a data link established in the H. P. G. control room.

In those cases where the reliability and performance will not be seriously affected, equipment will be "time shared" by several inputs or outputs to reduce capital expenditure.

In the following sub-sections, the proposed method is outlined in greater detail and examined in the light of the requirements of section 2.

3.1 Operator - /360 Communication

3.1.1 /360 Messages to the Operator (see Figure 3)

When the /360 has a message to pass to the operator, this message must be stored in a suitable output area of main storage. An "execute channel program" instruction, issued by the particular sub-program wishing to send the message, will start off a channel program which takes over the function of transferring data and releases the C. P. U. for other processing. The output device address, the output area and message length in the channel program will be nominated. The data channel will first determine whether or not it can commence to execute the data transfer by trying to locate the addressed device and sensing its status. If the device is ready to receive data (indicated by a "ready" signal to the 1827), the channel will suspend the operation of the C. P. U. at the end of a main storage memory cycle. When the C. P. U. operation has been suspended, the next storage memory cycle will be used to transfer one byte (i. e. 8 bits) of data from the output area to the addressed device (in this case one of the digital outputs of the 1827), control then being passed back to the C. P. U. which carries on with its current task. When the communication console has started to print the character represented by the digital output, it will send a "busy" signal to

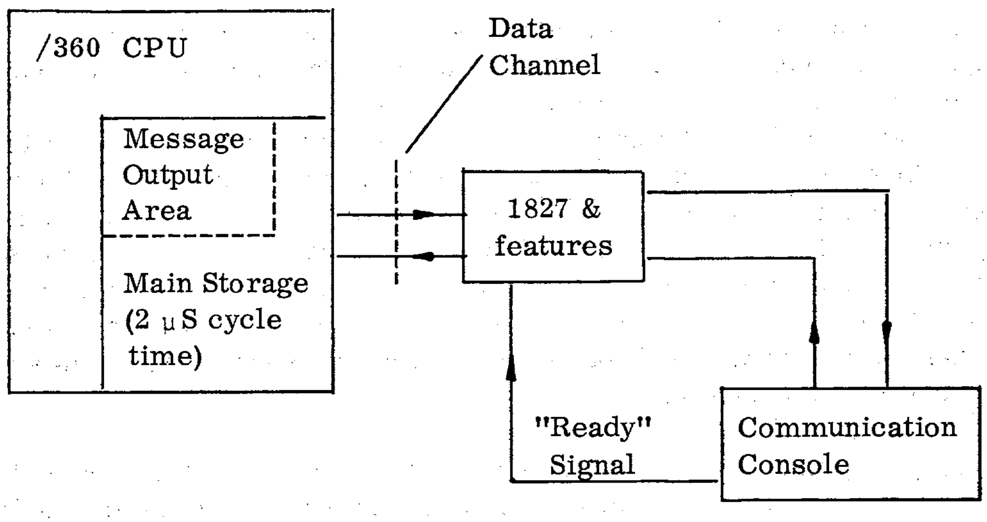

Figure 3. /360 Messages to the Operator

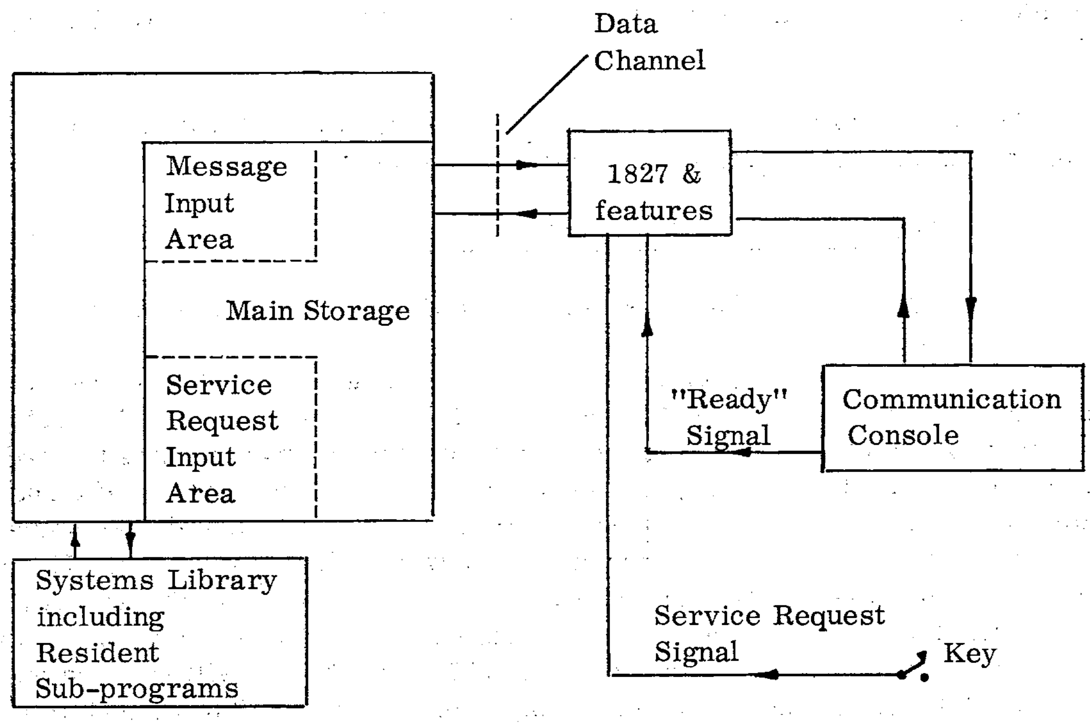

Figure 4. Operator Messages to /360

the 1827. This signal will persist until the character has been printed and the typewriter is ready to receive another character, the "ready" signal then being sent. The channel program will detect the "ready" signal and send another character. The data transfer will continue in this manner until the complete message has been placed. The process whereby the operation of the C.P.U. is suspended for a storage cycle is referred to as "cycle stealing". At the completion of data transfer the channel will inform the particular sub-program involved, via an I/O interrupt, that the message has been placed. In the multiprogramming environment, this will occur only after some interrupt priority processing by the operating system's supervisor, but apart from time delays (dependent on the sub-program's priority) this processing will not be perceived.

3.1.2 Operator Messages to /360 (see Figure 4)

For the operator and control system functions to communicate with the computer system at random times, some method of alerting the computer to various service requests is needed. The usual method of achieving this is to interrupt the computer via the /360 Direct Control Feature. This feature is not installed on the A.N.U.'s computing system and to avoid the high cost of installing it, an alternative approach is suggested. The digital input to the 1827 is available in modules of 16 points, each module appearing as a separate input device to /360. A data-channel program can be written to read one byte of data from this input module and place it in a fixed location in main storage whenever a "ready" signal for this module is received. The "ready" signal will be activated by a request for service after a coded message, designating the origin and general type of service request, has been placed on the digital input terminals. The channel will signal the main line program, via an I/O interrupt, that it has just read a new byte of data from this input point, whereupon the main line program will decode the service request, call into main storage a suitable sub-program and inform the point issuing the request to proceed. In the case of operator messages to the /360, service will be gained via a "service request" key on the communication console, the request being acknowledged by a "PROCEED" message from the /360 to the operator. The operator will then type a codeword indicating the specific service that he requires. A second sub-program (the first being one to handle communication console input generally) will be called into main storage to handle this specific request. On being told to "CONTINUE" by the /360, the operator will list any input data necessary for the request to be serviced.

Messages between the operator and /360 could be in conversational English but a fairly rigid format will be required. This limitation will not apply to documentation messages such as might be used by the operator for recording the cause of certain malfunctions for later reference. Within the various sub-programs, there will be a strict order of priority, with malfunction and emergency handling sub-programs assuming control, regardless of what other sub-programs were operating. This assumption of control will be achieved by suspending other less important operations.

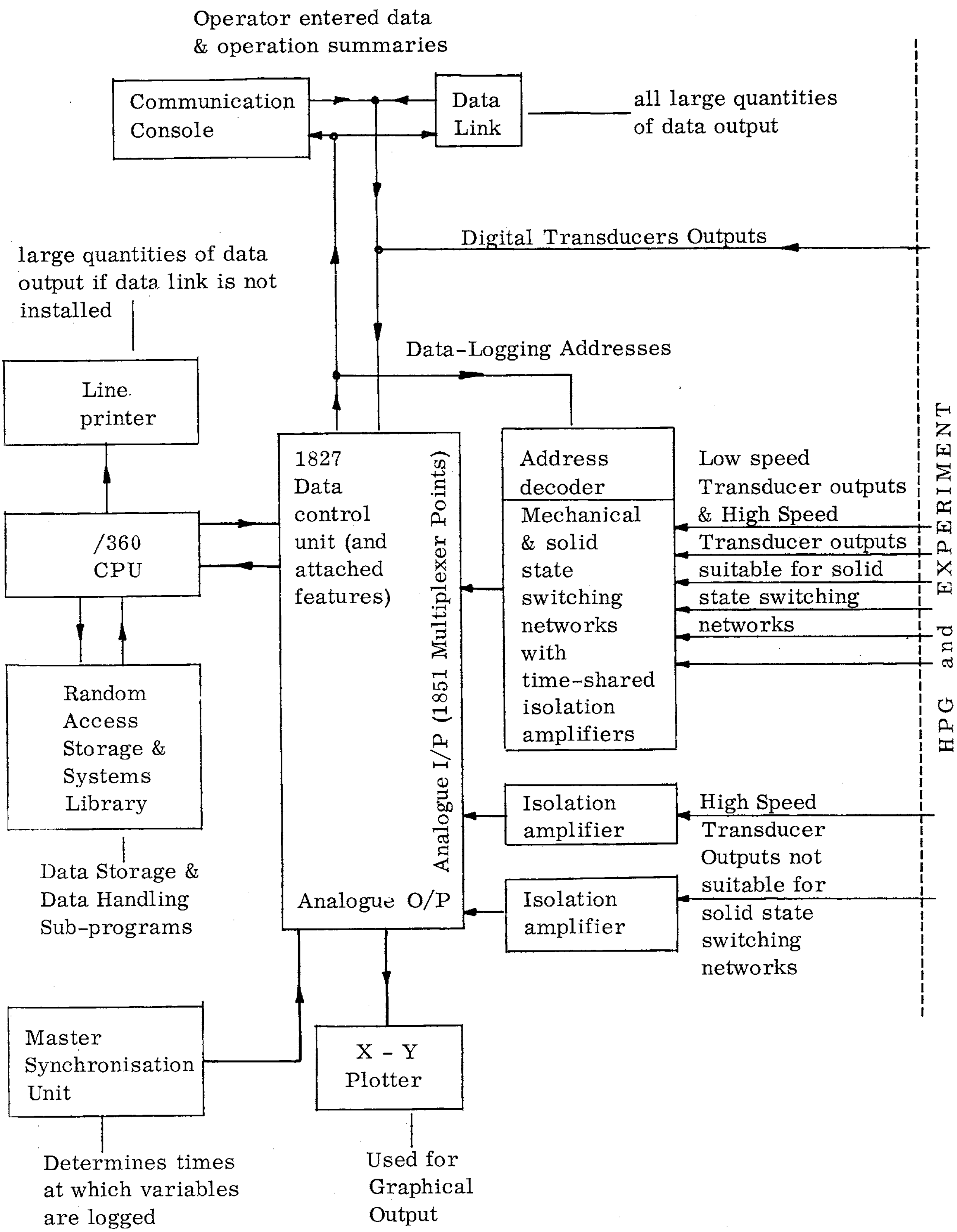

Figure 5. Data Handling

If the main-line program and sub-programs do not recognize any message from the operator, they will respond with a "MESSAGE NOT RECOGNIZED", rather than by aborting. They will then return to the point where they were originally ready to receive the (unrecognized) message.

It is important to note that in some cases, the /360 may have an urgent message to pass to the operator while the operator is passing a message such as a request for data transfer, to the /360. The operator could be warned of the occurrence by an auditory or visual alarm. A better solution might be to use the data link recommended in section 3.2.6 for all operator messages to the /360, except for the case where the operator is answering questions asked of him by the computer, the communication console then being used.

3.2 Data Handling (see Figure 5)

3.2.1 Data Acquisition

The outputs of the various transducers will be referred to by /360 via the analogue or digital input features of the 1827 data control unit, depending on whether they are analogue or digital in form. The 1851 unit is a high speed solid-state multiplexer which can, in conjunction with the A-D converter, digitize up to 10,000 samples per second taken from random or sequential points. Transducers requiring a sampling rate of less than approximately twenty samples per second will be connected via mechanical or solid state switching networks to time-shared isolation amplifiers and 1851 multiplexer terminals. By making the switching networks randomly addressable, the various sub-programs can sense the output amplitude of any of the transducers. The address of the transducer required will be supplied to the switching networks by a digital output module of the 1827.

A number of spare input lines will be made available for additional information regarding either the H.P.G. or the experiment and as a back-up in case of failure of a switching network or isolation amplifier. Transducers requiring a high scanning rate will be connected via their own isolation amplifier or attenuator to an 1851 multiplexer terminal, unless a high speed solid-state switching network is suitable.

A solid-state switching network is suitable only for reasonably high signal levels and low circuit impedances, unless a reduction in speed of operation is allowable (because of the need to allow transients to settle before sampling the output). Solid-state switching networks will not be suitable for applications in which there is a difference in common-mode voltage of greater than 10 volts or so between the channels to be addressed.

A "read" instruction, issued by the sub-program acquiring the data, will nominate the order and addresses of the inputs to be read, the actual instant of reading being synchronized externally by means of a "ready" signal. This signal will allow for the time delay necessary for the closing of mechanical and solid-state switches together with the associated amplifier "settling" time.

3.2.2 Data Logging[2,3]

The simplest approach to data logging is to set a scanning rate for every variable which, for any phase of operation, is sufficiently fast to cover all contingencies. Every sample taken would be recorded, with all data being printed out at the end of a day's run. This approach has two major shortcomings, firstly an excessive quantity of data is collected, thus using up large blocks of storage space in the computing system and secondly, it is difficult to pick out the data of interest from the mass which is presented. By examining various factors, it is possible to vary the scanning rate to suit the particular circumstances and to decide which of the acquired samples to record. In this manner, a large reduction in the volume of data recorded becomes possible. The first of these factors is the importance of the particular variable. During any phase of the H. P. G. 's operation, some variables will be of direct interest, some of indirect interest and others of little interest. An example is the case of motoring the H. P. G., where the rotor speeds and motoring brush currents are of direct interest, the various oil pressures and temperatures are of indirect interest and the pulse current--supposedly being zero--is of little interest. For the variables of direct interest, such as pulse current during a pulse, sufficient readings to accurately plot the variable's history may be required. This will involve scanning rates of up to several hundred points per second. In other cases of variables of direct interest, such as rotor speeds during the motoring phase, a far lower scanning rate (of say two points per minute) will suffice. For variables of indirect interest, it may be sufficient to record typical values every few minutes. If a malfunction is detected, an increased scanning rate will be used. For variables of little interest, it may not be necessary to record any values, unless a malfunction is detected. Another factor to be considered in reducing the amount of primary data gathered is the expected maximum rate of change of the variable being logged or monitored, during any phase of operation. This maximum rate can usually be estimated from physical considerations, such as the rate of decrease of oil pressure for a burst oil line, if not from past experience. The maximum allowable interval between samples (i. e. the minimum sampling rate) for each variable can thus be determined for each phase of operation. This minimum sampling rate will in many cases be set by the need to detect a malfunction without undue delay and to allow accurate recording of associated sudden changes. In a typical case, the operator must be informed of a malfunction within a few seconds, but during normal operation the recording of one sample every few minutes will be satisfactory. It is clear that a large percentage of the samples taken during normal operation need not be recorded. If some external method (to /360) is available of detecting a malfunction without undue delay, a slow scanning rate can be used until a malfunction occurs, a faster scanning rate then being employed.

3.2.3 Data Processing

Because of the adverse environment and the long leads necessary to connect some of the transducers to their associated meters and amplifiers, a fairly large noise component will often be present in the signal received at the control room. If the noise component can be described statistically or defined mathematically, a sampling rate and mathematical process which will yield a considerable improvement in signal to noise ratio can usually be found. The greater the difference in the characteristics of the signal and noise, the easier such a process is to find and apply. As an example, a slowly varying d.c. signal distorted by a large component of a.c. 50 cycle mains pickup, will be measured more accurately by taking the average of two samples spaced 10 mS apart than by taking a single sample.* In other cases, particular variables are of such importance that they will each be monitored by several transducers, perhaps using different physical principles. A form of correlation will help discover the variations common to the different transducers for each variable, i.e. the signal (and common noise). A type of majority logic processing can also be applied, with a warning being sent to the operator in the event of disagreement. Functions such as these can be achieved using special purpose circuitry operating on the transducer outputs, but the digital computer approach is more flexible and may be used to determine the optimum characteristics for any discrete circuits which are to be installed.

Another aspect of the data processing requirements is the processing needed on some transducer outputs (e.g. the insulation monitor), when the transducer output is not a linear function of the variable being monitored (i.e. the insulation resistance). In other cases it may be desirable to use calibration results and correction factors to obtain a more accurate measure of the variable being monitored.

3.2.4 Data Reduction and Compression[4]

In addition to the methods already outlined in section 3.2.2 for reducing the amount of primary data, further reductions can be effected by not recording the readings from transducers measuring such quantities as temperatures and pressures, unless they are outside normal operating limits. If this latter method is used, it is possible that in some cases of a malfunction being detected, the variable's prior history (with that of related variables) will be required and this would not be available. Although this method substantially reduces the amount of data recorded, it should not be applied unless operating experience indicates that satisfactory performance will be achieved.

Another possible method of reducing the volume of stored data, without losing essential information, is to record transducer readings only when they differ from the previously-recorded reading by a given percentage, say 1%. This method will reduce the overall accuracy by the percentage specified

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* This method of sampling relies on there being no appreciable even harmonics in the distorting waveform and is based on the principle that for each odd harmonic two samples 10 mS apart will be equal in magnitude but opposite in polarity, the sum of these two samples ideally being zero.

but this can be varied to suit the measuring accuracy and importance of the particular variables. A search for the closest recorded value will have to be made if the operator requests the value of a specific variable at a previous time. This problem will not occur in printing out the results sequentially, since the current value will be stored in main storage to enable the missing readings to be filled in.

As far as the computing system is concerned, the saving of random access storage space will have to be balanced against the additional central processor time necessary to achieve this saving.

3.2.5 Data Format

The most economical form for data storage in /360 is in simple binary. The unit of information is an eight bit "byte" which yields 256 possible combinations, i.e. a least count of 0.4% of the total. This accuracy should be adequate for logging the data associated with the H.P.G. and can be increased, when necessary, for storing experimental data. Within the C.P.U., this one byte of data will be accompanied by an additional one or two bytes of identifying information such as channel (transducer) number, time of day and polarity. When the records are stored on the 2311 disk drive, they will be written in blocks based on the time of day. Each block will have a header record, which will contain detailed identifying and status information and a count field indicating the length of the associated block in bytes. This header record will be followed by the data records of two bytes each--one byte for data magnitude and one byte having seven bits as a channel identifier and one bit as a data polarity indicator. The absence of a record for any particular channel will mean that either the channel had not been read at the time given in the header label or that its value had not deviated from the previously recorded value by a sufficient amount to require a new record to be written. The channel numbers with a high scanning rate can have a large number of entries in any given block. These readings can be synchronized externally, in which case no further timing information will be required. If readings are taken at a time nominated by the C.P.U., an additional byte giving more accurate timing information can be attached to selected data records. Alphanumeric data (such as messages and instructions to the operator) can be stored away as complete messages, or as words, phrases and symbols from which required messages and instructions can be synthesized.

3.2.6 Data Output

There are at least four different output devices which can be used, each device having its own application area. These devices are:

(a) The operator's communication console.

(b) The high speed line printer in the computer centre.

(c) An X-Y plotter attached to the analogue output feature of the 1827.

(d) An additional data link to be set up in the H.P.G. control room or other suitable location.

The operator's communication console must not be used for putting out large quantities of data while the H. P. G. is in operation, since it is likely that the data output will have to be interrupted while the /360 passes control and warning messages to the operator and receives replies. The communication console will be best suited to the output of short data summaries that are of interest to the operator. One function of the "main-line" program will be to keep a running summary of the H. P. G.'s operation. This summary will log the maximum and/or minimum values for as many variables as are required, together with details relevant to each entry. A log of detected malfunctions will also be kept. At the end of a day's operations, these summaries will aid the operator in deciding what data will have to be retrieved from storage before the storage areas are released to the computing system. Another type of summary will be a report presented to the operator at the conclusion of each pulse and will include such items as:

(a) Date, time of start and finish of the pulse and pulse number.

(b) Peak load current

(c) Rotor speeds and directions before and after pulse

(d) Field current

(e) Charge transferred

(f) Output voltage

(g) Any malfunctions detected during pulse

(h) Data relating to the electrolytic switch

(i) A summary of data relating to the experiment

(j) Sufficient information to reconstruct the current waveform in an approximate manner.

It is anticipated that the computer's high-speed line printer will be used for all large quantities of data output in printed form. Added flexibility will be achieved by installing an additional data link for the H. P. G., using the same approach as that outlined for setting up the communication console (see section 3. 1). An important feature of this addition will be that no additional load will be placed on the line printer by the implementation of the H. P. G. control and data logging programs. Another feature will be that data will be available in the control room with little delay and the need for traffic between the computer centre and the control room will be eliminated. Since the electric typewriters are relatively slow speed output devices (about 15 characters per second), data which are known to be required permanently will be printed out as they are acquired. Apart from reducing the peak loading on the typewriter, this technique will also save on the usage of random access storage in the computing system. By installing the data typewriter next to the communications console, the situation where the computer wants to communicate with the operator but cannot because the operator is typing out another message on the console, will be avoided (as explained in section 3. 1. 2).

The analogue output of the 1827 will be used to operate an X-Y plotter. Plotting will normally be as discrete points but can be arranged as a straight line segmented graph. The X-Y plotter can be situated in the H. P. G. control room or at some other convenient location.

To initiate data output, the operator will request service on the communication console and then request a suitable data formatting sub-program which will, in turn, ask the operator for the necessary parameters such as channel numbers required, starting time and finishing time. The data formatting sub-program will be responsible for binary to decimal translation, editing and documentation. For maximum accuracy, the analogue transducer outputs will be amplified or attenuated to have a full scale value approaching the $\pm$ 5 V maximum input level of the A-D converter. Because of this, each stored binary value will be multiplied by an appropriate scale factor before being converted to decimal.

The editing capabilities in /360 are quite extensive and the output can be presented in a wide range of formats, varying from sparsely documented groups of decimal digits up to fully documented decimal data with insignificant zeros suppressed and transducer descriptions, times of reading, decimal points, and units of reading being included. Various sub-programs can be called to perform differing degrees of editing and documentation, depending on the immediate need.

3.3 Management of Malfunctions in the H. P. G. and the Experiment (see Figure 6)

3.3.1 Introduction

Involved in the operation of the H. P. G. are several factors such as oil supplies, air supplies and insulation levels, the correct performance of any one of these being vital. By monitoring the outputs of transducers associated with these factors, an early warning of possible failure can often be obtained. From the large amount of accumulated data relating to the performance of the H. P. G., a picture of normal behaviour of these various outputs has been formed. In most cases upper and/or lower limits of amplitude and rates of change for satisfactory performance can be estimated. These limits may depend on functions such as rotor speed and whether or not a pulse is in progress. By detecting malfunctions in the critical factors at an early stage, steps can be taken to minimise damage, typically by bringing the H. P. G. to a halt.

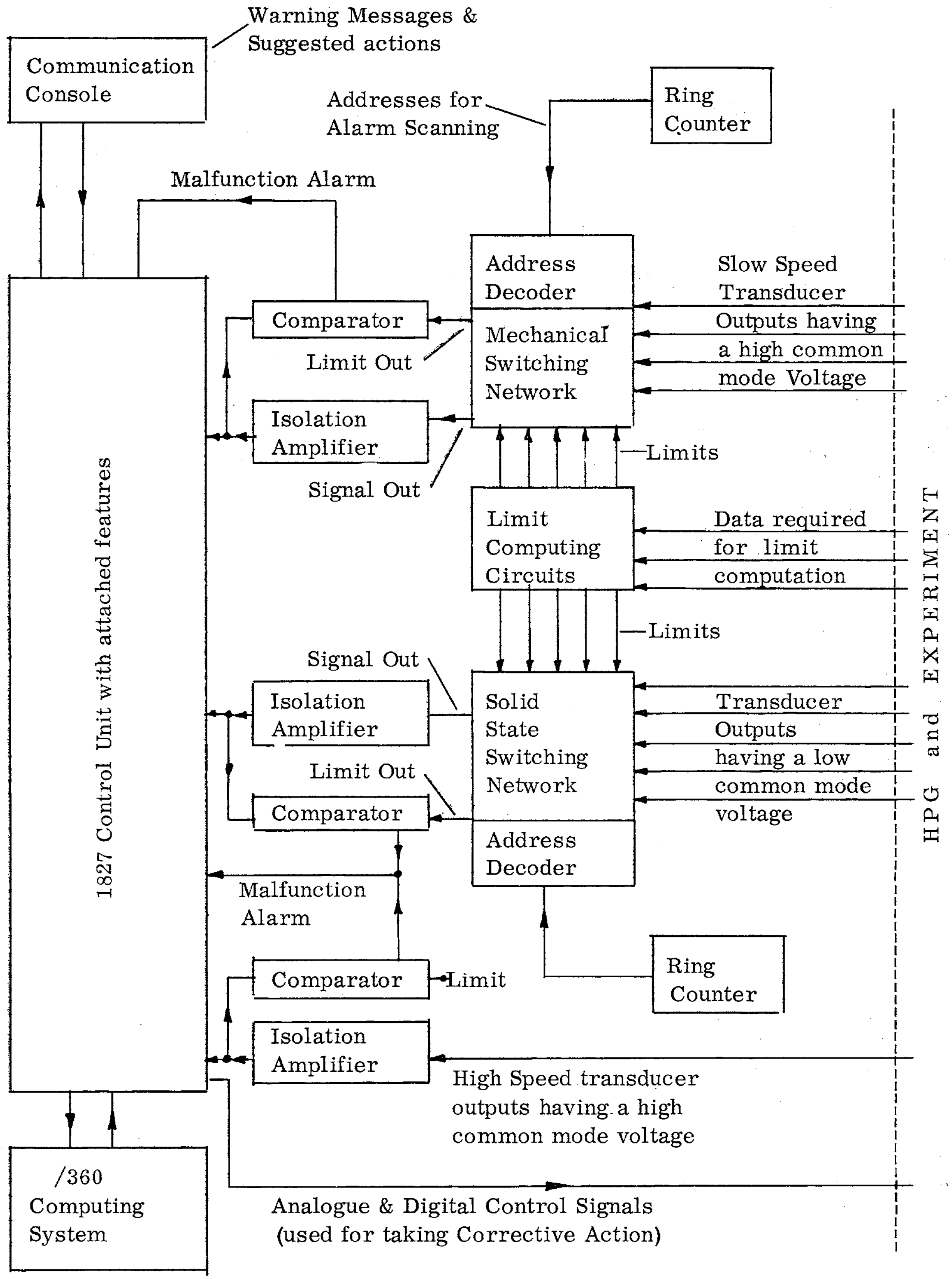

Figure 6. Malfunction Handling

3.3.2 Alarm Scanning[3, 5, 6]

As was mentioned in section 3.2.2, the scanning rate necessary for the various transducers from malfunction detection considerations, is often considerably higher than that necessary for data logging. In such cases, all the samples taken would be checked for limit violation but only a small percentage would be stored as data. Two possible approaches to the limit comparing function are to perform this either inside the computer by programming or outside with special purpose circuitry which will alert the computer if a malfunction is detected. The second approach involves some additional circuitry but this will be more than offset by the reduced demands made on the computing system. To be able to effectively supervise all transducer outputs, readings should be limit-checked every few seconds, whereas for data logging, a burst of readings every few minutes will be satisfactory, for a large proportion of the time that the H. P. G. is in operation.

Most of the transducer outputs to be checked for limit violation will be connected in groups (such as temperatures, pressures, insulation levels and rotor positions) via mechanical or solid state switching networks and isolation amplifiers to 1851 multiplexer terminals. Additional banks of contacts on the uniselectors or switching relays can be used to set upper and lower limits for each input. As each input is selected it will be compared with its limits. During the interval between bursts of data logging, the switching network can be made to sequence through the inputs with one complete cycle about every five seconds or in whatever time is considered necessary. For those transducers connected to 1851 terminals via their own isolation amplifier, a mechanical (uniselector) switching network can be connected to the amplifier outputs, for the purpose of alarm scanning a number of such transducers. Any limit violations will be used to interrupt the computer and call the malfunction handling sub-program into operation. So that the variable giving trouble can be continually monitored without interfering with other operations, a spare uniselector (having sufficient contacts to address any of the transducers) coupled to an isolation amplifier and 1851 multiplexer terminal, will be available. As well as monitoring the transducer outputs, each uniselector and isolation amplifier pair can to some extent monitor itself by having two standard inputs, one of zero volts (to check amplifier drift) and the other of say +4 volts (to check amplifier gain and comparator operation).

As has already been mentioned, some of the limits of allowable operation will depend on such factors as rotor speed and whether or not a pulse is in progress. To present the correct limits to the comparators, some analogue computation will be necessary in these cases. Additional circuitry will also be required when the rates of change of variables as well as the magnitudes are to be checked.

During the data logging operation the switching networks will operate at maximum speed, to reduce the length of time spent on the /360. The switching networks will be synchronized with the computer (or vice versa) during this operation and to simplify this function, an additional bank of contacts can be used to generate binary transducer channel addresses which can be entered via the digital input feature of the 1827.

A special circuit will be required for the rotor position monitor. Small transient deflections in the rotor might not be detected by taking samples of rotor position once every few seconds and some form of peak detection could avoid the use of a faster scanning rate. Unfortunately, the rotor position monitoring circuit is subject to large amounts of extraneous noise such as rectifier spikes and brush noise and these components will have to be removed by low pass filters before any satisfactory peak detection could be achieved. In the event of a high peak reading the spare isolation amplifier will be switched to the monitor output indicating trouble and a high-speed burst of readings will be taken so that the rotor perturbation (or indication of it) can be reconstructed.

It may be desirable to employ a degree of majority-logic processing where more than two transducers measure the same variable, so that in the event of a limit violation some elementary decision-making about the existence or otherwise of a real malfunction can be performed before the computer initiates further action.

3.3.3 Malfunction Handling[7]

An indication of a malfunction will cause a malfunction handling sub-program to be called into core storage by the main-line program. The first function of this sub-program will be to try to determine, by means of examination of related variables and execution of check routines, whether the malfunction is real or only apparent. If the check routines indicate that no real malfunction exists, a message with the relevant information will be passed to the operator and the decision as to whether to override bringing of the H. P. G. to a halt will be left to the operator.

When the H. P. G. is turning at speed and a real malfunction is detected, a complete assessment of the operation and status of the machine will be required before a decision is made with regard to the best manner for reducing its speed. Such an assessment can be made fairly readily when the machine status and malfunction are purely hypothetical and when there is ample time to consider the various alternatives. In actual operation, delay in introducing corrective action could have serious consequences and only a short time may be available to reach a decision. The digital computer, by virtue of the fact that it has all the information concerning machine status immediately available, will be able to perform this decision-making very quickly and it will not be a difficult task to catalogue the various methods for halting the H. P. G. and the prerequisites for each method. By listing these methods for trial in the order of least severe (reversing the main field and regeneration) to most severe (the emergency water brake) the method which causes least disruption will be arrived at.

The implementation of malfunction handling can be undertaken in three stages. In the initial stages of operation, the sub-programs will pass messages to the operator informing him of malfunctions and other related information. A second message suggesting a course of action will then be sent. If the operator decides that the course of action suggested is not appropriate he should document his reasons so that suitable additions and alterations to the sub-program can be made. If the operator decides that the course of action suggested is appropriate, it will be up to him to see that it is implemented, since, in the initial stages computer control will not be operational and the malfunction handling sub-program will not have the ability to act on its own advice.

When the malfunction program has evolved (by correction of any mistakes) to the point where it is operating satisfactorily and automatic controllers are available to the computer, the sub-program will not only suggest a course of action but will, with prior approval from the operator, carry it out. It is possible that after an extended period of satisfactory operation in this mode, the computer could be allowed to look after a range of malfunctions without having to obtain prior approval from the operator. The time required to check the operation of the malfunction handling sub-program can be reduced to quite reasonable proportions by using a "simulated" H. P. G. which would simply consist of potentiometers and switches at the inputs of the various data acquisition networks. A malfunction will be simulated by adjusting a voltage to a point outside the allowable limits and current machine status will be indicated by the various other switches and potentiometers.

If so required, a set of "warning" limits, tighter than those defining a malfunction, can be introduced so that the operator can be informed of impending malfunctions. It is anticipated that by receiving prior warning of a malfunction, the operator or, eventually, the automatic control system, will be placed in a state of vigilance and can take steps to see that conditions are corrected before a malfunction occurs.

3.3.4 Alarm Scanning for the Experiment

Any of the functions available for alarm scanning of the H. P. G. can be made available to the experiment. Associated with the switching networks and isolation amplifiers provided for the acquisition of experimental data will be facilities for setting limits and alerting the computer of violations. These violations could be handled by standard sub-programs resident in the system's library (on 2311 disk drive) or by special sub-program written for the particular experiment being conducted. If necessary, an additional set of digital input and output points could be installed on the 1827 data control unit and a direct communication link between the staff performing the experiment and the computer system could be set up. In this manner all of the data handling and processing facilities of the /360 could also be made available to the experimenters and a link with the H. P. G. operator would be provided.

3.4 Automatic Control[8, 9, 10]

Once the data logging and alarm scanning functions have been installed, most of the information necessary for the application of several levels of automatic control will be available to the computer. Some items of information, such as "test bay clear of personnel", are difficult to monitor electronically and when such information is required the computer will ask the operator to furnish it, via the communication console.

To put the computer's control decisions (arrived at by processing the available information) into effect, a number of servomechanisms, relays and decoding matrices will be required. Apart from these devices, however, the implementation of automatic control to almost any degree of complexity will only involve additional computer programs and computer time, together with transducers for required variables not already monitored electrically.

The lowest level of automatic control will involve tasks such as maintaining the rotor speeds constant prior to pulsing. The next level of control will co-ordinate these and other elemental control processes involved in particular phases of the H. P. G. 's operation, such as the motoring phase.

At the highest level of control all phases of the H. P. G. 's operation will be co-ordinated, including the alarm scanning and malfunction handling routines. When this stage has been reached, the control program will be given data relating to the required output from the H. P. G. and will proceed to calculate the conditions and configuration necessary to achieve this output. After the correct configuration has been obtained (either manually or automatically) the control program will bring the auxiliaries into operation, motor the H. P. G. up to speed and hold it in a condition "ready to pulse" until signalled by the operator, then proceed to take the pulse and continue the motoring-pulsing cycle (with or without operator initiation of each pulse, as required) until the required number of pulses has been taken and the H. P. G. can be shut down.

The powerful computational and logical facilities of the computer system can be very useful in automatic control applications which are difficult to realize using normal servomechanism techniques. This is particularly true of situations where a hierarchy of control methods is available. With simple feedback type control systems. there is a tendency for the various methods of control to interact adversely. An example of such a system is a pulse current control which uses the electrolytic tank position, resistive shunts across the electrolytic tank, and forcing of the main H. P. G. field as methods of control. By examining the pulse current and knowing the characteristics of the various controllers, the computer control program can make them work in harmony to achieve a better result than that normally obtainable. A further advantage of the powerful on-line computing facilities available is that adaptive and self-adjusting control systems can be used in situations where optimum performance is desired. A typical situation where these systems yield superior results is the simple position control servomechanism. With a predictive type control system, a step input causes maximum acceleration until the controlled object is approximately half way to the desired position and then maximum deceleration until the controlled object reaches the desired position. It will have just become stationary as it reaches this position and therefore there will be no overshoot and the time necessary to reach the final position will be a minimum.

The implementation of an overall system of automatic control will be undertaken in stages, with the elemental control systems being developed first and operating smoothly before the higher levels are attempted. In implementing the various phases of automatic control, a minimum of interference to existing instrumentation and interlocks will be made, so that during the evaluation of the various digital realizations of these functions, manual control can easily be re-instituted if necessary.

It should be noted that there will be many applications in which a measure of discrete control circuitry will be preferable to a purely digital solution. The concept of hybrid circuitry will be examined in cases which otherwise would involve continuous attention by the digital computer. Another aspect of the hybrid approach is that functions such as addition, subtraction and time integration which are performed satisfactorily by analogue methods, can be performed externally to the digital computer and so release computing capacity for the tasks which are more easily handled in a digital environment.

It will probably be worthwhile to evaluate and adjust proposed discrete systems by first incorporating them as digital programs. After these systems have been adjusted, by program change, to perform satisfactorily, they can then be implemented as discrete circuitry. This approach takes advantage of the flexibility of the digital computer during the development of the "circuit" and will allow the complete automatic control system to be implemented sooner than if a large quantity of discrete circuitry is required initially. A further advantage will be that the load on the computing system will tend to decrease rather than increase with the evolution of the control and alarm scanning systems.

The automatic control systems already in satisfactory operation on the H. P. G. will not be superseded, but rather, supervised by the digital programs.

In addition to the control facilities available to the H. P. G., the various inputs from the associated experiment can form the basis for any control, synchronization and co-ordination functions to be performed for the experiment. The availability of the data logging and supervision facilities, in combination with the functions mentioned above, will be of immense value in reducing the amount of special equipment required to perform these tasks for experiments which will use the H. P. G. as an energy source. By changing the appropriate programs, a wide range of experiments could be performed with a minimum of setting up time and delay in acquiring the associated control equipment. In the place of the large amount of the "hardware" usually required, will be "software" resident in the systems library or stored away in "off-line" storage such as punched cards. A further important advantage of realizing some of the various service and control functions in the computing system is the ease with which such functions can be adjusted or expanded when compared to the equivalent discrete circuits.

3.5 The Relationship between the H. P. G. Programs and Other Users of /360.

It is assumed in the following discussion that by the time the H. P. G. programs are operational, the computing system will support multiprogramming. The computer programs to be used in conjunction with the H. P. G. will be operating in an "on-line" (or real time) environment.[11] This means that if buffering stores are not used, data will be lost unless the computer services the data acquisition facilities as the data become available. Similarly, unless control decisions made by the computer are implemented while the information on which they have been based is still current, serious mistakes could be made. In contrast to this situation, the normal "off-line" computer user is merely inconvenienced by delays in execution of his compilations and programs, because his data is static. For these reasons, the "on-line" user may require service to his requests with much less delay than that acceptable to the "off-line" user.

The various programs being executed on the computer will be assigned a priority. When two or more programs are competing for the same facility of the computing system, the program with the highest priority will take precedence. The computing system will appear to each program as if it alone is operating, but those with the lowest priority will appear to be operating in a fairly slow system while those with high priorities will, apart from task-task transition and priority processing delays, operate at much the same speed as they would on a single program system.

At the present moment there are two other users whose operations could possibly be classified as "on-line". The first of these is the link between the /360 and the I. B. M. 1800 processor-controller being used by the Nuclear Physics Department of A. N. U. Discussions with Dr. Hibbard of the above department have determined that no data will be lost if the /360 does not respond to a service request within a reasonable period, but that inconvenient delays in processing will result. It is acceptable for the H. P. G. programs to take precedence over the 1800 link, provided that delays of more than five seconds in response from the /360 to requests for service from the 1800, are unlikely to occur. Such delays will in fact be rare because the likelihood of both the 1800 and H. P. G. requesting service at the same time is small and even in the case where the H. P. G. programs are operating, their use of the C. P. U. 's time should be sufficiently small to allow concurrent processing.

The second of the "on-line" operations is the seismic data processing being performed by Mr. Muirhead of the Department of Engineering Physics of the A. N. U. In this application, the input data is recorded on magnetic tape and will not be lost if the computer fails to service the data input unit, although some inconvenience will result from having to reprocess data by rewinding the magnetic tape. Such a failure is not likely, however, as this data will be transferred into input areas of core storage via a "cycle stealing" operation and the processing will be done in a conventional "off-line" manner. The 1827 data control unit and some of its facilities will be used in the transfer of data from the magnetic tape to the computer. The H. P. G. program will use these same facilities, and to save duplication, Mr. Muirhead has agreed to perform his processing at times when the H. P. G. programs are not being used.

With both of the above "on-line" users, there is no real danger of any data being lost and a priority as high as that required by some of the H. P. G. programs will probably not be necessary.

The proposed data logging and alarm scanning functions of the H.P.G. program have been arranged so that minimum interference and delay to other users of the /360 will result. This is achieved in the following ways:

(a) During normal data logging operations (i. e. not during pulses), the data will be logged in high speed bursts of about 1 second approximately once every two minutes. The C. P. U. would be in use for only a small fraction of this second. This approach will reduce the interruptions to other programs and the time spent seeking disk areas that would be experienced if the data logging is spread over the two minute interval.

(b) A large proportion of the limit checking for various transducer outputs will be done externally to the computer and only in the event of a malfunction will the computer be called.

(c) Data logging during pulses will be performed using two input and two output areas in the central processor. The input readings will be externally synchronized and the C. P. U. will be used by the H. P. G. for only about 20% of the interval between successive readings. This small usage will allow time for the C. P. U. to handle other programs concurrently. The main source of interference between programs will be the additional "seek" time involved when the H. P. G. programs and other concurrently operating programs are accessing the same 2311 disk drive.

It is suggested that the programs associated with the H. P. G. which depend on a fast response from the computing system should be given top priority. The percentage of computing system time used will be small and the effect on "off-line" jobs should not be discernible. If this suggestion is not completely acceptable, the data acquired for data logging could be read into fairly large input areas in core storage and then put onto a disk drive to be processed later "off-line". The malfunction and control routines would still require a high priority, however.

3.6 The Relationship between the H. P. G. Programs and Other Users of the 1827 Data Control Unit

While the H. P. G. program is in operation, it will not be satisfactory for another user to address the same input and output terminals of the 1827. The equipment used by the H. P. G. program is electrically connected to these terminals and relies on the data path for communication with the computer system in the event of trouble. There will be a number of terminals of the 1851 multiplexer which are not used by the H. P. G.

and the analogue output facility will be available to other users. The 16 bit digital input modules and 16 bit digital output modules used by the H. P. G. will not be available. Fortunately, the 1827 data control unit, together with its input and output control and adapters has the capability to expand to a large number of addressable input and output points for both digital and analogue information. By adding a sufficient number of these points, the 1827 data control unit could be used simultaneously in two or more applications with little interference. As has been pointed out in section 3. 1, the 1827 data control unit can be used to form a control unit for an input-output typewriter and it is possible that other users may have an application for such a communication system.

3.7 Additional Facilities

The link between the computer and the H. P. G. operator (via the 1827 data control unit and the communication console) enables the operator to have available many of the computational and data handling facilities of a large scale computing system. These facilities will be made available by the "main line" program, which will recognize the operator's code-word requesting a particular service and call into main storage a suitable sub-program. The sub-program itself can be entered via the communication console, but a simpler solution will be to load this program into the system's library from punched cards. The facilities mentioned below are possible examples:

(a) All sampled values of selected variables could be printed out on the communication console until a given time or until the operator dispenses with this function.

(b) A summary of the maximum and/or minimum values of selected variables together with other relevant information could be outputted on the communication console or the line printer.

(c) Processing sub-programs could be called to operate on data entered via the communication console or located in random access storage.

(d) A check on losses in the H. P. G. could be made by calculating the input power necessary to maintain constant speed, or by calculating the loss power expended from the rate of change of rotational speed with no input power. This function would require several readings over a period of 3 or 4 minutes.

(e) A calculation of the conductivity of the electrolyte in the electrolytic switch could be made from data acquired during the last pulse. This data would include pulse current, depth of immersion of plates, electrolyte temperature and voltage drop across the switch. The calculation could perform an estimate of the conductivity for several points during the pulse and so give an indication of the change in conductivity with time and temperature.

4. NEW EQUIPMENT REQUIRED

If the system outlined in section 3 is to be implemented, sections 4.1 to 4.9 detail the major items of new equipment which will be required. Section 4.10 gives approximate costs for the basic system and the additional costs for some extensions to this system.

4.1 Additional Features Needed for the 1827 Data Control Unit

The 1827 data control unit will have analogue input and output facilities installed, but for communication with the operator and control systems, together with manipulation of digital input and output, digital facilities will be required.

For digital output, a digital output control (A$430), digital output adapter (A$430) and several sets of digital "electronic contact operate" (E. C. O.) outputs of 16 bits each (A$580 ea.), will be required. The number of E. C. O.'s will depend on the range of control and communication functions to be performed. A minimum of three of these outputs is suggested (one for supplying addresses to multiplexer networks, one for operator communication, and one for digital control).

For digital input, the digital input basic feature (A$2,000), digital input adapter (A$580) and several sets of "digital input contact" 16 bit inputs (A$230 ea.) will be needed. Again, the number of inputs required depends on the range of functions to be performed and a minimum of three is suggested (one for service requests, one for operator communication and one for digital input from transducers).

Any additional facilities to be used on the 1827 should be ordered from I. B. M., without delay, because of the due delivery date of A. N. U.'s own unit (i. e. as opposed to the rented unit at present installed).

4.2 Decoding Matrices

To translate the various digital signals from the computing system to meaningful control signals for the automatic controllers and transducer accessing networks and to translate the signals from these devices into meaningful signals for the computer system, coding and decoding matrices will be required. Each of the digital input and output modules of the 1827 has 16 bits. From combinations of these 16 bits, up to 65,536 input or output messages could be coded (but this would require an excessive number of diodes in the decoding matrix). Using sixteen diodes for each line carrying a message to (or from) the H. P. G., any output (or input) line being "on" would correspond to a definite combination of the 16 bits coming from (or going to) the 1827.

The matrices will not have to operate at very high speeds and fairly slow (and cheap) diodes could be used. About three matrices, each having eight lines one way and perhaps 30 lines the other way, will be required.

4.3 Electric Typewriters

One electric typewriter, e.g. an I.B.M. "Selectric" at about $1200 will be required for the communications link between the computing system and the operator. Additional communication facilities such as data links will require additional typewriters. A data link using such a typewriter will remove the need to use the computing system's line printer and for this reason alone the data link could be worthwhile.

4.4 Switching Networks

To reduce the capital expenditure required for isolation amplifiers and additional 1851 multiplexer points, together with the need to perform limit checking externally to the computer system, several sets of randomly addressable solid state or mechanical switching networks will be required. These networks will sequence through the inputs at about two points per second during alarm scanning but will be required to operate at about twenty points per second during data logging and to be able, on command from the computer, to address any input. A uniselector bank could be used, but some additional circuitry would be required for random addressability. Associated with the network, electronic addresses will have to be generated and, in some cases, upper and lower limits provided for each point being accessed. Comparators, such as the Fairchild μA711C, will be needed to perform the limit checking.

Mr. Cantor of the Department of Engineering Physics has developed a (relay based) switching network which, with modifications to permit random addressing, should be satisfactory in the applications for which a mechanical multiplexer is required. In other cases a solid-state switching network using dual-emitter transistors will be more suitable. Details of suitable switching networks for the various transducers on the H.P.G. are outlined in section 7.2.

4.5 Isolation Amplifiers

Although most analogue transducers will require an isolation amplifier during the period that their output is being digitized, some isolation amplifiers can be shared by several transducers by means of the switching networks of section 4.4. The problem of selecting suitable isolation amplifiers is examined in section 7.1 and the circuits chosen are shown in section 7.2.

4.6 Electronic Controllers

Fortunately, since most of the control of the H.P.G. in its present form is performed via electronic signals from the control room, only relatively small powers are required to exercise these control functions. The analogue and digital outputs of the 1827, after suitable power amplification, could exercise these same functions. There are other functions such as the closing of air lines during shut down, which are not controllable electronically and if these functions are to be available to the computer programs, electronically operated controllers will have to be installed. Additional controllers will be required when the computer programs start performing control functions, such as fine pulse-current control, which are not at present installed.

4.7 Additional Transducers

Associated with the installation of the controllers mentioned in section 4.6, additional transducers will be required so that the computer programs can be made aware of the position and performance of the various controlled functions. Some of the functions are now reported verbally to the control room operator, and these will have to be monitored electronically so that the computer programs can be automatically informed, if it is not convenient for the operator to enter suitable reports by the communication console.

A few variables, such as diesel generator output frequency, water pressures, and oil pressures are monitored in the H. P. G. by meters which are not operated by a d. c. voltage (but by a. c. voltages and bourdon-type gauges) and additional transducers will be required to present a d. c. voltage dependent on the variable being monitored.

The outputs of some transducers have large noise components or are affected by extraneous switching surges. These effects could easily cause out-of-limit readings and unless the malfunction handling sub-programs can be made to differentiate between such indicated malfunctions and actual malfunctions, it will be necessary to reduce these extraneous effects, possibly by installing new transducers.

4.8 Interlock Override Controls

It sometimes occurs that in an emergency or failure, the presence of some interlocks can be embarrassing, the purpose for which they have been installed being at that moment irrelevant. It is possible that after due consideration of matters of safety, in exceptional circumstances the computer program could be given the ability to override certain interlocks. If this procedure was agreed upon, interlock sensing transducers and override controls will be required.

4.9 Alarm-limit Computation Circuitry

The alarm limits for some variables are not fixed but will vary with machine conditions. An example is the case of the rotor expansion monitor where the allowable expansion is a function of rotor speed squared; a radial expansion of .015 in. from the 100 r. p. m. size being allowable at 900 r. p. m. but this expansion being limited to .004 in. at 450 r. p. m. In such situations, to save virtually continuous attention (once every 5 seconds) from /360, special purpose analogue computing circuits could usefully be employed. It is anticipated that the total cost of these circuits would not exceed $400.

4.10 Master Synchronization Unit

To relieve the computing system of the burden of deciding when to perform the various readings for data logging, a master clock will be required to synchronize the operation of the slow speed multiplexers mentioned in 4.4 with the operation of the high speed 1851 multiplexer and analogue to digital converter. This synchronization unit could be based on a crystal oscillator with binary dividers and gating circuits, operated by the various slow speed multiplexers, which would prevent the 1827 and 1851 from taking readings until the required transducers have been accessed and the amplifiers have settled. This unit would also initiate bursts of data logging at whatever interval is required. Alternatively, the synchronization unit could be based on the electronic clock already installed in the H. P. G. control room, with the addition of some logic circuitry and a 10 k. c. oscillator.

4.11 Estimated Costs of Implementation

(a) Basic System

			$
(1)	Digital Input and Output for 1827	÷	5,870
(2)	Decoding Matrices	÷	500
(3)	Switching Networks	÷	1,000
(4)	Isolation Amplifiers	÷	765
(5)	Master Synchronization Unit	÷	200
(6)	Other Logic Circuits	÷	200
(7)	Alarm Limit Computive Circuits	÷	400
(8)	Power Supplies	÷	300
(9)	Contingencies	÷	400
(10)	Typewriter	÷	1,200
		÷	$10,835

(b) Additional Costs

(1)	Data Link - Typewriter	÷	1,200
	Additional Digital input and output modules for 1827	÷	810
			$2,010
(2)	Alarm Limits - per transducer, μ A711C comparator	÷	18
	Contribution to power supplies and additional logic circuitry	÷	20
	Approximate cost		$38

5. SUMMARY AND CONCLUSIONS

Methods of implementing a system of data logging, automatic control, and alarm scanning for the H. P. G. and associated experiments have been examined. Details of a proposed system have been given in section 3 and this system has been examined for compliance with the requirements of section 2. In general, these requirements may be satisfied at a reasonable cost (see section 4.10).

In section 3.2 it is shown that data logging can be performed with a minimum of manual effort and the data so acquired can be processed, documented, edited and summarized so that its interpretation is greatly simplified.

Automatic control can be provided in a wide range of applications for both the H. P. G. and the experiment, as outlined in section 3.4. Full use can be made of the digital computer's flexibility in implementing and altering the various controls.

In section 3.3 it is pointed out that the performance of a wide range of supplies and functions can be monitored automatically with a greater level of awareness and precision than that attainable manually. In the event of impending failure of any critical functions, use can be made of the computer program's speed and up-to-date information to decide on the best course of action and either to implement this directly or via the operator. By the use of alarm limits, early warning of poor operation of most functions can be given, so that emergency action may sometimes be avoided.

An effective but relatively cheap on-line link with the powerful facilities of the computing system, can be established by using an I/O electric typewriter connected to the 1827. This link enables the operator to use the facilities of the computing system and to select a wide range of sub-programs for performing specific tasks relating to the operation of the H. P. G. and experiment as well as to the processing of acquired or operator entered data. The 1827 data control unit is capable of expanding to handle a large number of such on-line links and it is possible that other computer users could find use for a system such as that outlined in section 3.1. The additional cost for each of these links would be approximately A$2, 010, including the cost of the typewriter.

The proposed system has been designed to cause as little interference as is practicable to other "on-line" and "off-line" users of the computing system, details of the methods used to achieve this being given in sections 3.5 and 3.6. The lack of buffering stores and the fast response time required for automatic control and emergency situations, require that some of the H. P. G. sub-programs be given a very high priority. By setting up inter-program communication areas, either in core or direct access storage, the H. P. G. sub-programs which can operate satisfactorily with a low priority, can be so assigned. With the increasing use of the computing system by the H. P. G. and other users, it may at some future stage be practicable to purchase a small additional computer to relieve the /360 of the bulk of the work associated with the H. P. G.

Interference to other users of the 1827 can be minimized by installing additional analogue input and output facilities. The present usage of the 1827 does not justify this expense.

Very little change to the existing control systems and instrumentation for the H. P. G. is needed and for this reason, the failure of any of the components in the new system will not put the H. P. G. out of action. It should be noted that some of the present transducer outputs are contaminated by noise and/or affected by extraneous switching surges. It may be necessary to reduce these effects, if necessary by installing new transducers, so that these extraneous signals do not cause out-of-limit readings. An alternative approach is to try to build into the computer sub-programs the ability to discriminate between out-of-limit readings caused by extraneous noise and those caused by an actual malfunction. The system reliability should be satisfactory, the most likely source of trouble being the mechanical components. To improve reliability by removing these components, it may be worthwhile to increase the number of isolation amplifiers and 1851 multiplexer points while reducing the number of mechanical multiplexers. This approach would involve additional cost, which can be offset by using the range of amplifiers outlined in section 7. 2. This cost will also be offset by the increased sampling rates possible and consequently the reduced time spent on the /360 during data logging.

The various functions of the data logging and control system can be most easily implemented in clearly defined stages, as outlined in section 2. 8, with each stage being in satisfactory operation before the next stage is attempted.

From the viewpoint of experiments to be conducted in association with the H. P. G. , the provision of data logging, control and alarm scanning functions which can be tailored and adjusted to suit the particular experiment in use, provides a very favourable experimental environment. These functions will be very helpful in reducing the amount of time required to set up any particular experiment. The data logging and processing system could present the experimenter with processed results and operation summaries within seconds of the experiment's completion, thus enabling quick decisions as to what course to take in the succeeding pulses. All of these factors would be of great assistance in increasing the experimental throughput of the H. P. G. , as well as to experimenters.

The effort involved in getting workable computer programs will be substantial This phase of the implementation can be simplified by the concept of a "main-line" program which simply recognizes requests for service and loads the appropriate sub-program into main core storage from the system's library.

The various sub-programs can be written and checked out by filling up their input areas with simulated data and service requests, when processing them as normal "off-line" jobs. Their output areas would be printed out on the line printer and interpreted to see if the sub-programs were operating satisfactorily.

Apart from the above services, the implementation of the H. P. G. programs will provide an extensive and valuable exercise in some of the techniques used for real time computer systems.

As detailed in section 4.11 the approximate cost of equipment required for implementing the basic system outlined in section 3, is $10,835. Of this amount $5,870 will be required for additional facilities (digital input and output) for the 1827 data control unit and these facilities could easily be employed by other computer users for such items as remote communication consoles. For this reason, the amount of $5,870 will not be attributable to the H.P.G. alone. If the data link mentioned in sections 3.1.2 and 3.2.6 is to be installed an additional sum of $2,010 will be needed. This sum includes an electric input-output typewriter together with additional digital input and output modules for the 1827. Only 8 of the 16 bits for each of these modules will be used by the data link, thus allowing an additional typewriter for any other application to be connected for approximately $1,200. If "warning" limits, as described in section 3.3.3, are to be employed, an additional cost of approximately $38 for each transducer so monitored will be involved. No attempt is made to assess the cost of additional controllers required for new control functions. For those functions already controlled electronically, the main costs involved will be in the provision of buffer amplifiers between the 1827 digital and analogue output and the various electronic controllers. No estimate has been made of the cost of installing the additional transducers (mentioned in section 4.7) for relaying those variables at present reported manually or not available as a suitable electrical representation.

A substantial amount of data logging is at present performed in the H.P.G. control room by the use of two ultraviolet oscillographic recorders. One of these recorders is used to log such variables as rotor position, pulse current, field current and electrolytic switch position, while the other recorder is used to log the temperatures and voltage drops of a large number of brushes. It is not considered feasible to replace these recorders by digital computer data logging because it would be necessary to make extensive use of the computer's storage areas and C.P.U. time. To record digitally those variables monitored by the U.V. recorders (with as much detail as is presently achieved) almost continual attention by /360 and high sampling rates would be required. The computer sub-programs will, however, be of great assistance in interpreting the U.V. records, by providing details and times of any unusual conditions observed.

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7.1 A D.C. Coupled Isolation Amplifier

7.1.1 Introduction

The 1827 data control unit accepts analogue input voltages having a maximum level of $\pm$ 5 V with respect to ground. Many of the transducers are mounted on parts of the H.P.G. which can assume large d.c. voltages with respect to ground. For insulation monitoring reasons, most of these parts have no direct connection to ground except through relatively high impedances. Because of this, large a.c. and noise components can be superimposed on the d.c. voltage. In other cases, as a result of the adverse environment and the long leads necessary for some transducers, voltages can be induced between the signal lines and ground. To avoid the passage of heavy currents in the signal lines (and the consequent error-voltages developed) single point earthing is often used. For reasons of transducer insulation and reduction of stray pick-up, it is sometimes desirable to perform the earthing at the transducer, thus causing common voltages to be induced at the control room end of each of the two signal lines. Because of these factors, some form of circuit is required which will separate the signal voltage from the common-mode voltage (i.e. the voltage common to both signal lines). As well as performing this separation, the signal will usually have to be amplified to have a full scale level approaching the $\pm$ 5 volt maximum of the 1827. For the above reasons, the separating circuits will be called "isolation amplifiers". It should be noted that the analogue to digital converter has an accuracy of .01% for a $\pm$ 5 Volt input, i.e. 0.1% for a $\pm$ 0.5 V input or 1% for a $\pm$ 50 m V input. In some cases it may be possible to save circuit costs by amplifying only to say 0.5 volts (or by not using an amplifier at all for high level, low impedance signals with no common-mode voltage.

7.1.2 Derivation of "Worst Case" Specifications

Each of the specifications derived below is a "worst case", so that an isolation amplifier satisfying each of these specifications can be used for any of the transducers already installed on the H.P.G. No transducer requires all of these "worst case" specifications at once and for most transducers some of the specifications can be relaxed considerably.

7.1.2.1 Accuracy

It is suggested that an overall accuracy of 1% of Full Scale in the conversion of a transducer's output voltage to a binary number in the computing system, should be aimed at. If each of the disturbing factors (such as drift in the amplifier) is treated as a normally distributed random variable, the effect of the "means" of these distributions can be taken account of by adjusting the gain and/or off-set voltage of the amplifier to cancel them out. The variance of the sum of a number of normal distributions is equal to the sum of the individual variances, if the distributions are not correlated. The standard deviation (= $\sqrt{\text{variance}}$) becomes equal to the square root of the sum of the squares of the individual standard deviations. From this fact, it is apparent that unless there is a correlation between the various sources of error, only the major sources of error need to be considered. Thus, for practical purposes, the quantization error of 0.4% (which can be made into a rounding error of ± 0.2% by the addition of a suitable voltage before analog to digital conversion) caused by using only 8 bits and the analogue to digital conversion error of .01% can be neglected in an overall accuracy of 1%. For causes of random error such as variations in voltage gain and offset voltage, the square root of the sum of the squares of the possible individual errors should not exceed 1%, or if it is felt that there could be some correlation between the errors, the sum of the absolute errors should not exceed 1%. In deriving the specifications for the isolation amplifier the worst case for all transducers is considered in arriving at each specification. Fortunately, no transducer combines all the worst features and so the measurement error for any one transducer will be less than the algebraic or geometric sum of the worst case errors.

7.1.2.2 Voltage Gain

The smallest signal voltages are those associated with the rotor-surface temperature-sensing thermocouples, which have a full-scale output of about 5 mV. This voltage implies a maximum overall gain of about 1,000 times. Again, as pointed out in section 7.1.1, it may be less costly to use a lower full-scale voltage than the ± 5 V maximum. The errors in voltage gain (neglecting drift for the moment) should be made as small as is practicable, a random error or better than 0.4% being satisfactory for this application. If other sources of error were low, this figure could be increased.

7.1.2.3 Input Impedance

The maximum Thevenin equivalent impedances for any of the transducer voltage outputs, considering the shunt impedances of moving coil meters and calibrating resistors, are the 600 Ω or so associated with the strain gauge oil-pressure transducers and the 1000 Ω associated with the rotor position monitor. To cause minimum disturbance to the transducer and existing instrumentation, the amplifier input impedance in these cases should be at least 100 kΩ. Provided that the transducer output impedance and amplifier input impedance stay reasonably constant, the reduction in signal voltage can be compensated by increasing the gain slightly. For this reason, the finite amplifier input impedance will contribute only small random errors and these can usually be neglected.

7.1.2.4 Common-Mode Rejection

The voltages of various parts of the H.P.G. with respect to ground, could possibly approach ± 1,000 volts (d.c. + peak a.c.). The smallest signal voltages have a full-scale level of 5 mV. An accuracy of better than 1% of full-scale implies that in the worst case, a common-mode rejection ratio of at least 146dB will be necessary at d.c. Since large portions of the H.P.G. are grounded to a.c. through only relatively high impedances, sparking at the brushes, rectifier spikes and other transients can introduce large components of a.c. into the common-mode voltage. Because of this, a high common-mode rejection ratio will be required at frequencies in the passband of the amplifier, i.e. up to about 300 Hz. Care is necessary in balancing the amplifier input impedances from both signal lines to ground, if a high common-mode rejection ratio is to be achieved.

7.1.2.5 Frequency Response

The low-frequency response must extend to d.c., as most transducers have a direct component in their output. The high-frequency response must accommodate the most rapid changes which are of interest in any of the signal voltages (i.e. noise and unwanted transients not being considered) and must also be sufficient to allow rapid sampling of many voltages with the one amplifier.

The rotor-position monitor will contain the highest frequency components (neglecting noise) and from observation of past records, together with analogue computer studies carried out by Mr. Blamey of the Department of Engineering Physics, these components could extend to about one hundred cycles per second. The peripheral rotor monitors have to respond to a calibration mark which would last for approximately two milliseconds at full speed. An accurate indication of this calibration would require an amplifier rise-time (to 63%) of about 0.5 milliseconds.

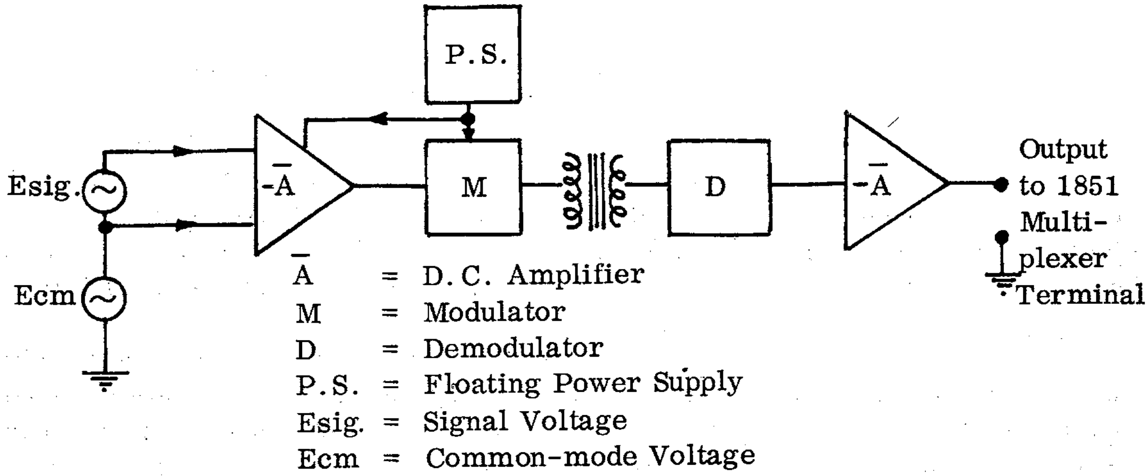
When the amplifier is being used to sample the outputs of many transducers by multiplexing, the maximum sampling rate will determine the high frequency response. The worst case would be when the amplifier is switched from a high level (say 100 mV) to a low level transducer (say 5 mV). The output will be required to settle to within 0.5% of its final value in a fraction of the sampling interval. As an example, this requirement would indicate an amplifier rise-time of about 0.5 milliseconds for a sampling rate of twenty points per second, which corresponds to an upper half-power frequency of approximately 300 Hz.

7.1.2.6 Drift Stability

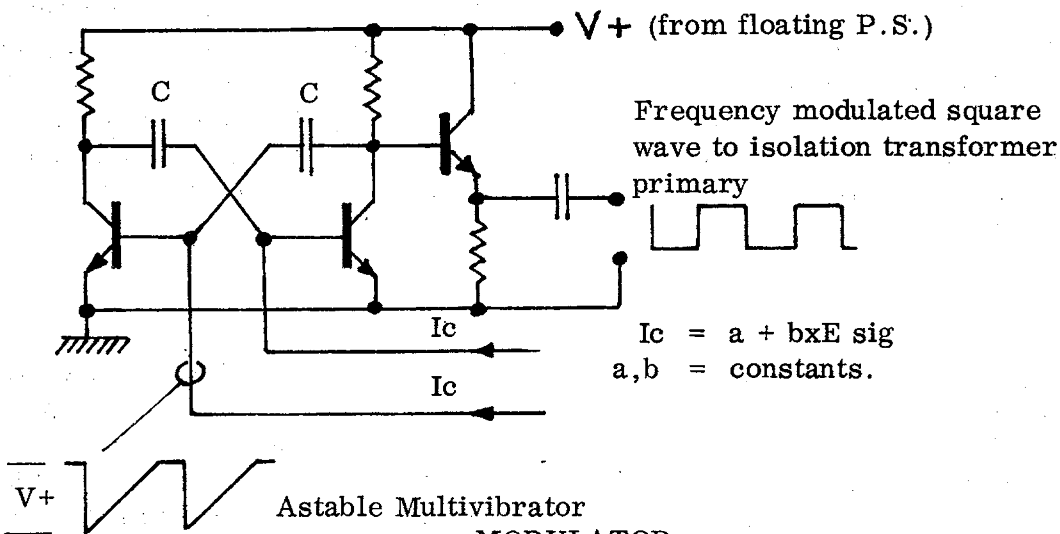
The lowest full-scale level of the transducer outputs to be measured will be the 5 mV of the rotor-surface-temperature-sensing thermocouples. For an error due to this cause alone of 1% of full scale, the total (input referred) drift from all causes should be less than $\pm$ 50 μV. This figure will have to be reduced according to the magnitude of other errors likely to be present. Typical causes of drift are the temperature dependence of amplifier offset voltage and current, transients introduced into the signal voltage by solid state modulators and very low frequency random noise in amplifiers. In this worst case, maximum values for any of these considered alone, assuming a 100 k Ω input impedance, and a $\pm$ 8 $^{\circ}$C operating temperature, will be

offset voltage drift	$\pm$ 3 μV/$^{\circ}$C
offset current drift	$\pm$ 3 pA/$^{\circ}$C
random noise	$\pm$ 5 μV peak

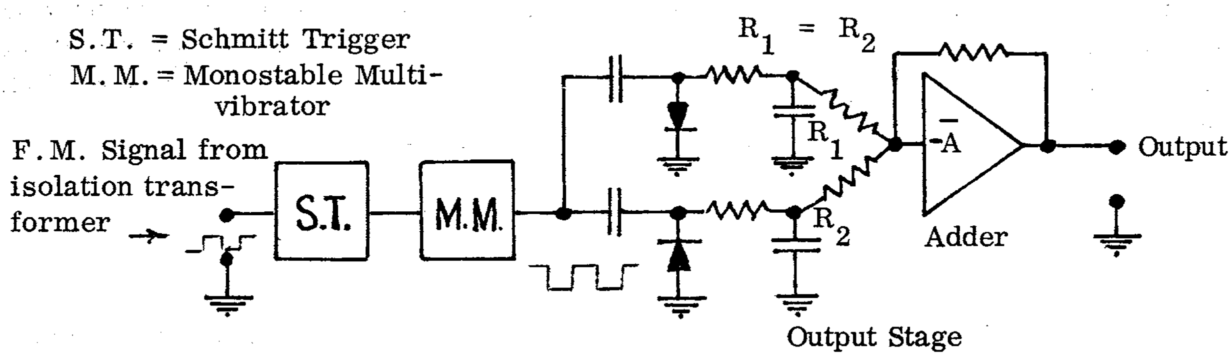
The allowable temperature dependent drift rates can be increased if the operating temperature range is reduced by thermostatic control.



FUNCTIONAL ARRANGEMENT



MODULATOR



DEMODULATOR

Figure 7. Frequency Modulated Isolation Amplifier

7.1.2.7 Cost

A large number of isolation amplifiers will be required. The number used will depend greatly on the cost, since, if the amplifiers are cheap, the most straightforward solution would be to use one amplifier for every analogue transducer. An advantage of this approach is that multiplexing the transducer outputs prior to the isolation amplifier would be avoided. If any multiplexing (outside of the 1851) was necessary, it would be then performed on the isolation amplifier outputs, where the signal levels are high, source impedances are low and there is no common-mode voltage. A solid-state multiplexer could be used with the attendant advantages of high speed and reliability.

7.1.3 Selection of a Suitable Isolation Amplifier

In the light of the specifications derived in section 7.1.2 a study was made of commercially-available isolation amplifiers. This study failed to find an amplifier which satisfied all the specifications, the closest approach being made by the Philbrick Researches SP2A. This amplifier was, however, unacceptable because of a $\pm$ 200 V limit to common-mode voltage and equivalent input drifts of $\pm$ 30 μ V/^{o}C and $\pm$ 100 μ V/day.

Because of the lack of suitable isolation amplifiers, an investigation has been made of a number of possible circuits and a range of application given for each circuit. [12] This investigation revealed that it was possible to construct an amplifier which would meet all the specifications of section 7.1.2 apart from the matter of cost (see Figure 7). To reduce overall costs, this amplifier will be used only when necessary and a suitable circuit for each group of transducers has been arrived at by examining the electrical conditions for each of these groups (see section 7.2).

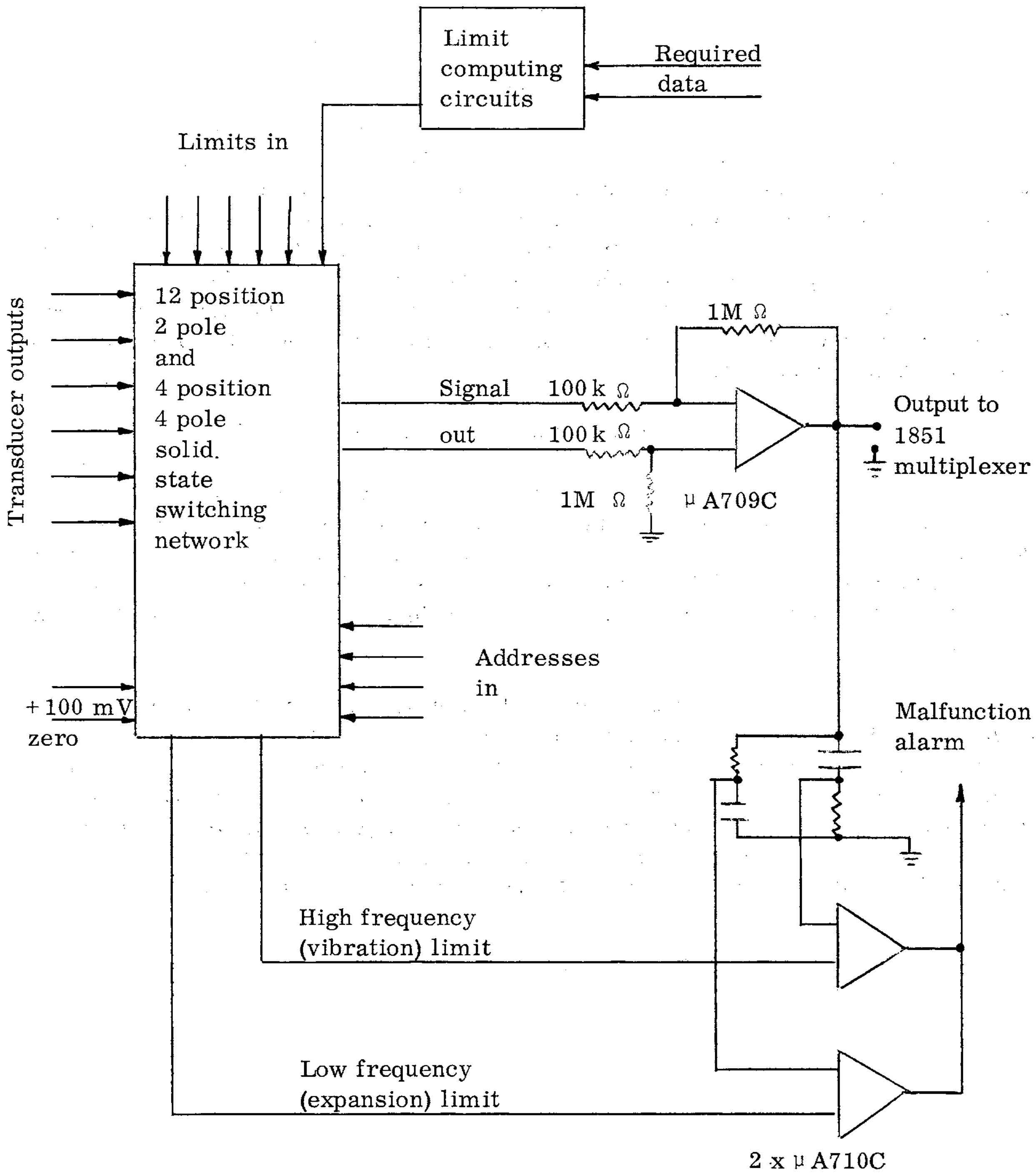


Figure 8. Rotor Position Monitor; Data Acquisition Circuit

7.2 Details Regarding Analogue Transducers Presently Installed on the H.P.G. With Suggested Groupings and Amplifier Circuits

Sections 7.2.1 to 7.2.10 examined possible groupings of analogue transducers at present installed on the H.P.G., describe the electrical signal received from these transducers, and suggest suitable switching and isolation amplifier circuits. A circuit for a general purpose isolation amplifier[12] is shown in Figure 7. No attempt is made to define the allowable operating limits for each variable but some of the factors which will have to be considered in fixing these limits are described.

Section 7.2.11 summarises the equipment required for the circuits given in sections 7.2.1 to 7.2.10.

7.2.1 Rotor Position Monitors

Fourteen transducers are used to sense changes of radial and vertical position for both rotors. The transducers utilise the change of capacity of a sensing plate (mounted close to the rotor) to vary the resonant frequency of a tuned circuit and thus yield an output signal which is a function of rotor position. Four vertical (N, S, E, W) and three radial (0^{o}, 120^{o}, 240^{o}) transducers are used on each rotor.

A suggested circuit for the switching network and isolation amplifier is shown in Figure 8.

7.2.1.1 Description of variables to be monitored for both rotors

(a) Lift of bearing face: formed by summation of the four vertical transducers

(b) N-S Tilt: formed by taking difference of N and S transducers

(c) E-W Tilt: formed by taking difference of E and W transducers

(d) 0^{o} Radial Position

(e) 120^{o} Radial Position

(f) 240^{o} Radial Position

(g) Rotor Expansion: Formed by summation of the three radial transducers.

7.2.1.2 Signal descriptions

Amplitude: $\pm$ 50 mV or 0 - 100 mV.

Source impedance: $\doteqdot$1 k Ω

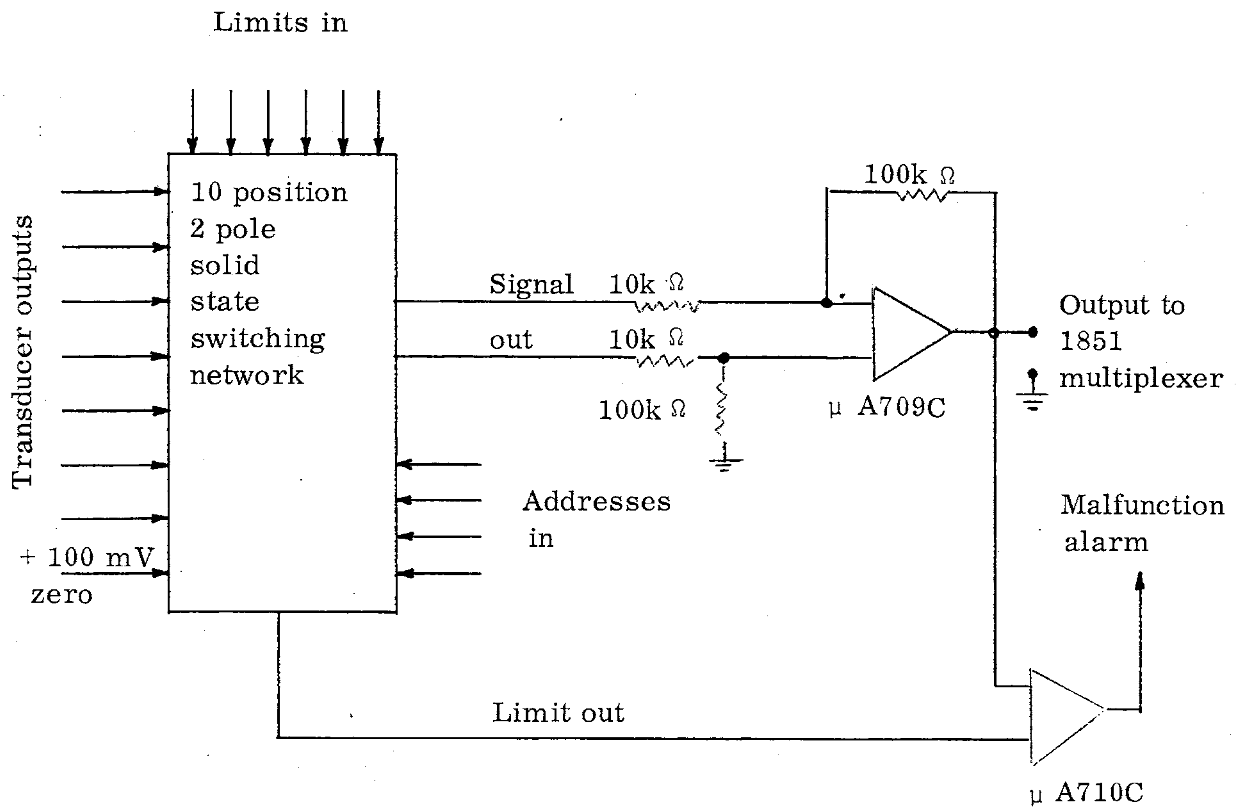


Figure 9. Insulation Monitor; Data Acquisition Circuit

Common Mode Voltage: induced noise only, for (a), (d), (e), (f), (g) up to 100 mV + induced noise, for (b), (c).

Frequency components of interest: d.c. to 100 Hz.

7.2.1.3 Data logging and alarm scanning requirements

Each variable should be logged once every two minutes when not pulsing. During pulses this rate will have to be increased according to the rotor speeds and length of pulse. Alarm scanning should be performed for each output approximately once every five seconds, this rate being increased upon detection of a malfunction.

7.2.1.4 Comments

The limits for normal operation depend on factors such as rotor speed, temperature and zero errors and some analogue circuits will be required to compute these limits. The allowable rotor expansion is a function of rotor speed squared and the zero errors should be regularly checked (when the rotor speed is less than 100 r.p.m.)

The deflection sensitivity is not linear with deflection but is a hyperbolic function. The normal distance between the sensing plate and the sensed object is about .030 in. and this can be changed .010 in. by deflection of the rotor, thus causing a marked change in deflection sensitivity. The computer sub-programs could correct for this change, however, and give a more accurate indication. Frequency components of the monitor outputs below 0.1 Hz correspond to rotor expansion while higher frequency components correspond to the variation in rotor position during each revolution. Limits will have to be set for the maximum amplitude of both these components.

7.2.2 Insulation Monitors

The insulation to ground of several parts of the H.P.G. is observed by applying 225 volts to these parts via a resistor and then measuring their voltage to ground. A suggested circuit for the switching network and isolation amplifier is shown in Figure 9.

7.2.2.1 Insulation levels (to ground) monitored

(a) Brush Group 0

(b) Brush Group 2

(c) Brush Group 6

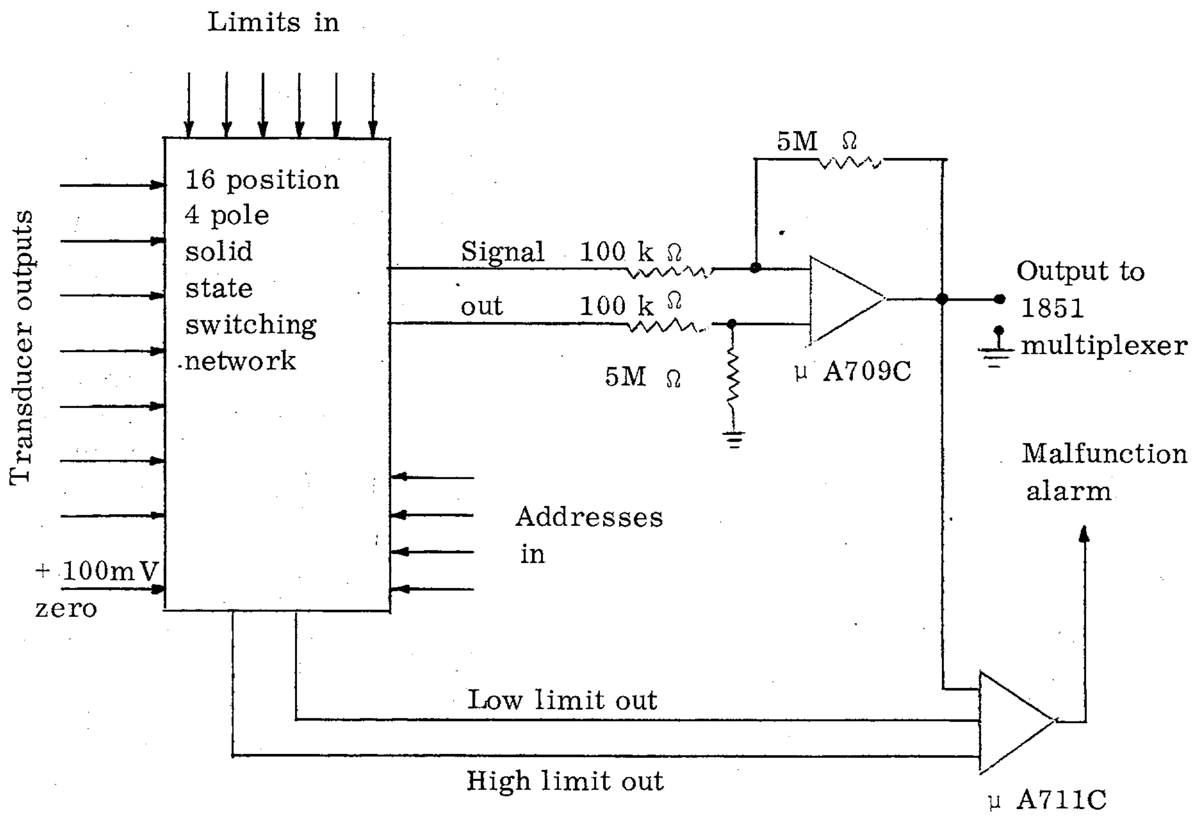


Figure 10. Oil Pressures;
Data Acquisition Circuit

(d) Brush Group 7

(e) Top Airpad

(f) Bottom Airpad

(g) Guard

(h) Spare

7.2.2.2 Signal description

Amplitude: 0 - 100 mV

Source impedance: < 100 Ω

Common mode voltage: induced noise only

Frequence components of interest: d.c. to 1 Hz

7.2.2.3 Data logging and alarm scanning requirements

Each insulation level should be logged once every two or four minutes and alarm scanned once every ten seconds, except during pulses.

7.2.2.4 Comments

The insulation monitors incorporate logic circuitry to prevent starting-up of the H.P.G. if any insulation level falls below a predetermined level. This logic circuitry is overridden during the preparation for, and taking of, a pulse. The limits of normal operation will generally be fixed at a certain minimum insulation level.

7.2.3 Oil Pressure Transducers

The pressures of various oil supplies and oil bearings are monitored by semiconductor or resistive strain gauges mounted in a resistive bridge The bridge is balanced at zero applied pressure and becomes progressively unbalanced as the pressure is increased, the unbalance voltage developed being a function of the oil pressure. A suggested circuit for the switching network and isolation amplifier is shown in Figure 10.

7.2.3.1 Description of oil pressures monitored

(a) Top rotor guide oil supply

(b) Top rotor thrust oil supply

(c) Bottom rotor guide oil supply

(d) Bottom rotor thrust oil supply

(e) Top rotor NE thrust bearing

(f) Bottom rotor NE thrust bearing

(g) Top rotor SE thrust bearing

(h) Bottom rotor SE thrust bearing

(i) Top rotor NW thrust bearing

(j) Bottom rotor NW thrust bearing

(k) Top rotor SW thrust bearing

(l) Bottom rotor SW thrust bearing

(m) Bottom rotor thrust bearing; backing pressure

(n) Top rotor thrust bearing; backing pressure

7.2.3.2 Signal descriptions

Amplitude: 0 - 70 mV for (m), (n); 0-20 mV for all others

Source impedance: ÷ 1 k Ω for (m), (n); ÷ 600 Ω for all others

Common-mode voltage: ÷12 V d.c. + induced noise

Frequency components of interest: d.c. to 1 Hz

7.2.3.3 Data logging and alarm scanning requirements

Each pressure should be logged once every two minutes and alarm scanned every five seconds.

7.2.3.4 Comments

Interlocks are installed to prevent starting of the H.P.G. if the backing oil pressure is low. The common-mode voltage of ÷ 12 V d.c. can be reduced by suitable alterations to the bridge power supplies. The limits for satisfactory operation will normally consist of a fixed upper and lower limit for each supply.

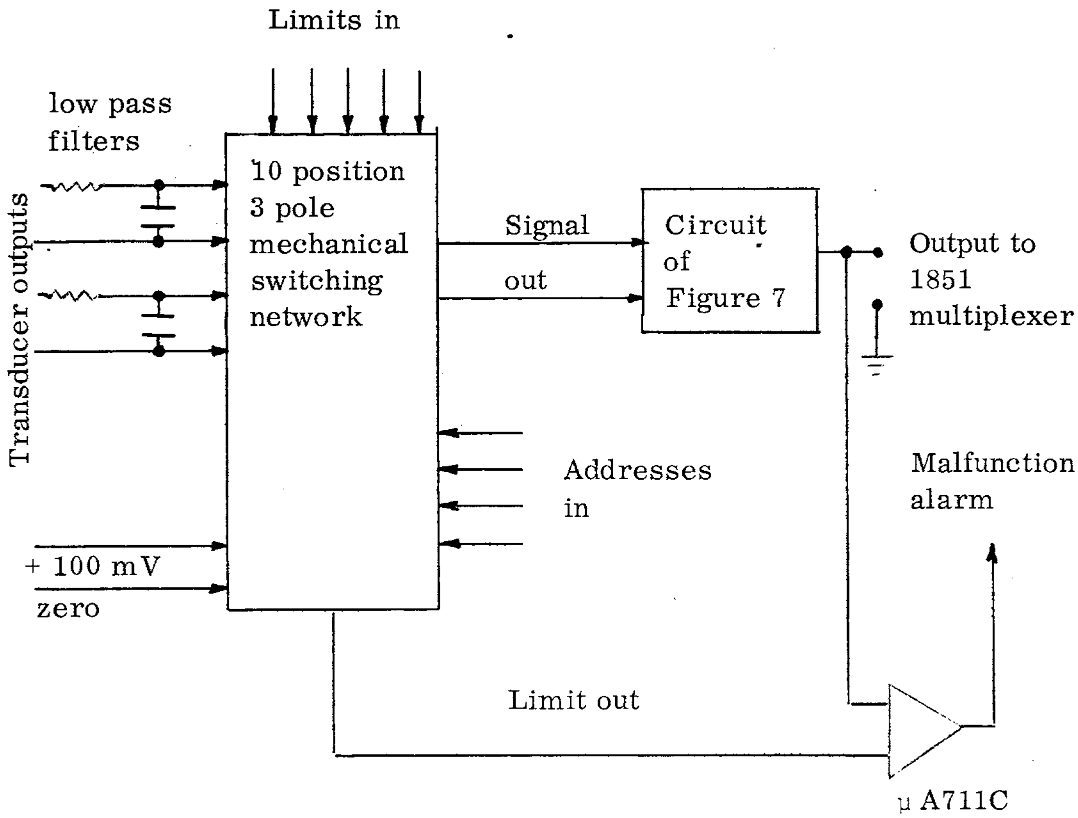


Figure 11. Motoring Brush Currents;
Data Acquisition Circuit

7.2.4 Motoring Brush Currents

Current shunts are installed in the leads to selected single brush sets and to larger groups of brushes. During the motoring phase, the brush currents may be observed to see if the brushes are sharing the total current in a reasonable manner. A suggested circuit for the switching network and isolation amplifier is shown in Figure 11.

7.2.4.1 Description of brush currents monitored

(a) Current for each of four single brushes on top rotor

(b Current for each of four single brushes on bottom rotor

(c) Current for each of four quandrants of brushes (bottom rotor only)

7.2.4.2 Signal description

Amplitude: 0 - 70 mV

Source impedance: very low

Common-mode voltage: up to $\pm$ 500 V

Frequency components of interest: d.c. to 1.0 Hz

7.2.4.3 Data logging and alarm scanning requirements

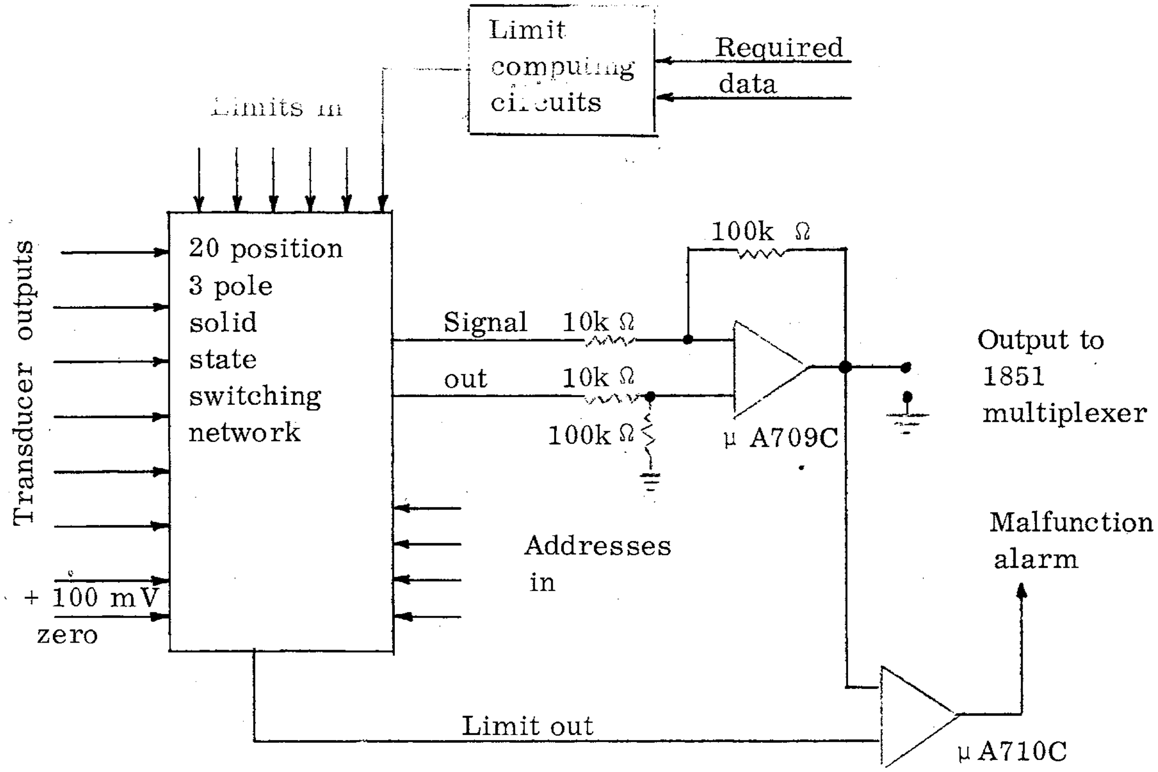
Each current should be logged at thirty second intervals and alarm scanned at ten second intervals.

7.2.4.4 Comments

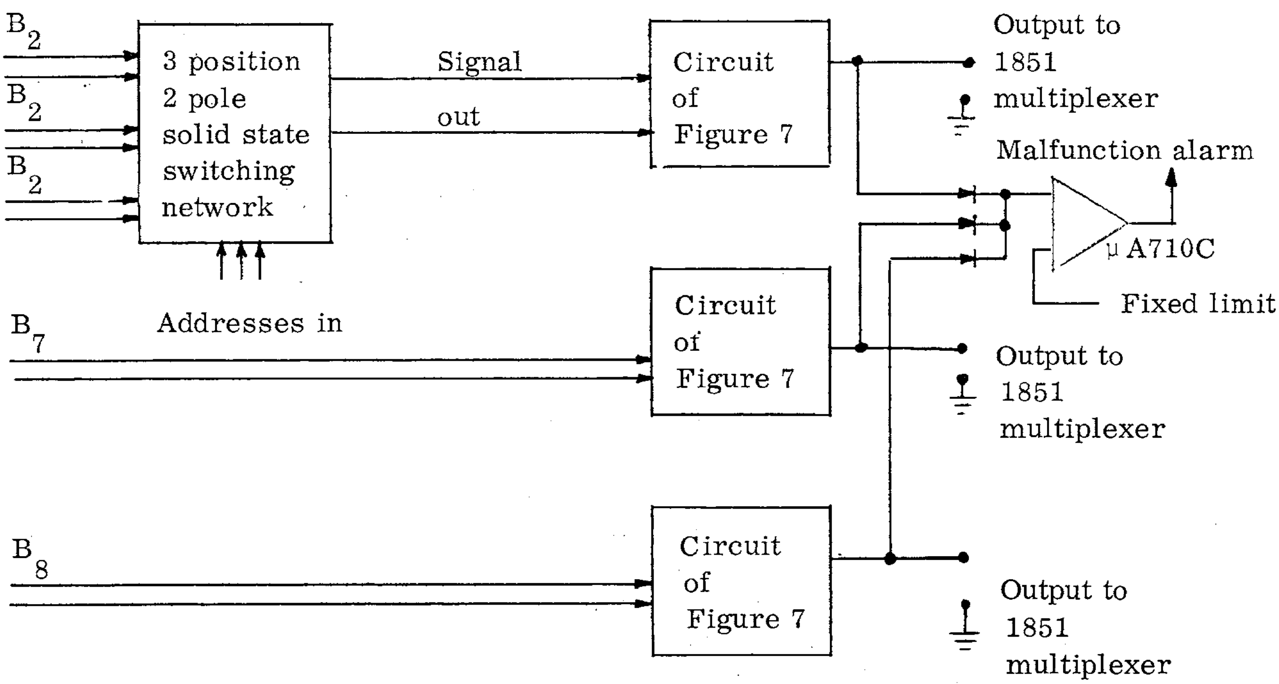
Large variations occur in the proportion of current taken by the individual brush sets and a low pass filter with a time constant of several seconds may be required for each current shunt, to average the currents taken. The limits for satisfactory operation will generally be fixed as a maximum average current. An indication of brush condition can be obtained by observing the range of fluctuations in and magnitude of the proportion of total current taken.

7.2.5 Temperatures

Thermocouples and thermistors connected in bridges are used to monitor a large number of temperatures within the H.P.G. The thermocouples used for measuring brush temperatures will be considered in appendix 7.2.9



Circuit for thermistor temperature sensors



Circuit for rotor surface temperature sensors

Figure 12. Temperatures;
Data Acquisition Circuits

and not here. Suggested circuits for switching networks and isolation amplifiers are shown in Figure 12.

7.2.5.1 Description of temperatures monitored

(a) Oil temperature from top guide

(b) Oil temperature from bottom guide

(c) Top thrust piston temperature

(d) Bottom thrust piston temperature

(e) Top airpaid temperature 1

(f) Top airpad temperature 2

(g) Bottom airpad temperature 1

(h) Bottom airpad temperature 2

(i) Ambient temperature: B1, B2, B7, B8; i.e. 4 only

(j) Temperature of oil into bearings

(k) Temperature of oil from bottom bearing

(l) Inlet air temperature; diesel compressor

(m) Inlet air temperature; mains compressor

(n) Thrust bearing outer edge oil temperature

(o) Rotor surface temperature: B2, B7, B8, B2, B2 moving, i.e. 5 only

7.2.5.2 Signal description

Amplitude: (a) - (n), 0-100 mV; (o), 0 - 5 mV

Output impedance: (a) - (n), < 100 Ω ; (o), low

Common-mode voltage: (a) - (n), $\doteqdot$10 V d.c. + induced noise. (o) - up to $\pm$ 1000 V.

Frequency components of interest: (a) - (n) - d.c. to 1 Hz. (o) - d.c. to 5 Hz.

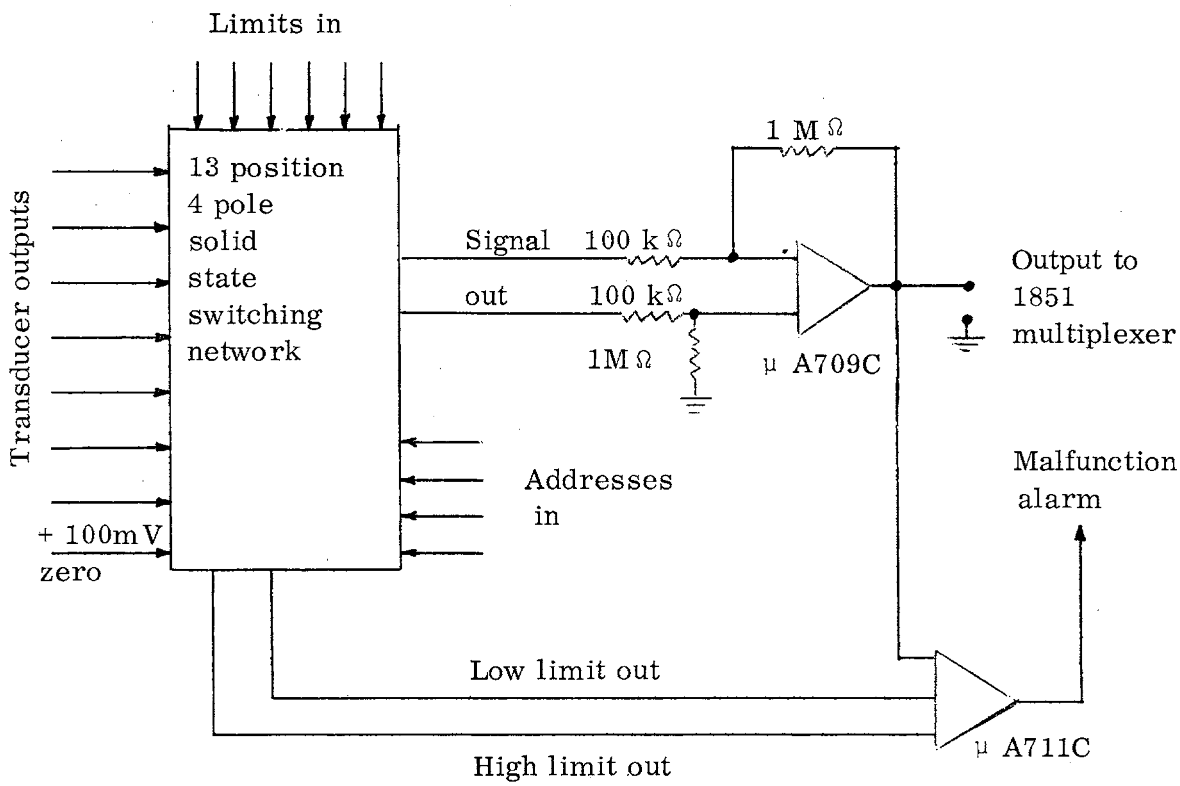


Figure 13. Air Pressures;
Data Acquisition Circuit

7.2.5.3 Data logging and alarm scanning requirements

All temperatures except (o) should be logged every two minutes and alarm scanned every ten seconds. The rotor surface temperature sensing thermocouples need be logged only when they have been lowered onto the rotor. Alarm scanning need not be performed on these thermocouples and a data logging rate of up to twenty samples per second, depending on the pulse length, may be necessary.

7.2.5.4 Comments

The d.c. common mode voltage associated with the thermistor probes could be reduced to a low level by rearrangement of the bridge power supplies. The high sampling rates necessary for the surface temperature sensors implies a solid-state multiplexer but to use these, three separate switching networks and isolation amplifiers will be required because of the high voltages likely to exist between B2, B7 and B8.

Some of the allowable operating limits will be fixed but others will depend on such factors as ambient temperature and rotor speed.

7.2.6 Air Pressures

The various air pressures are measured by two different types of transducers, i.e.

(a) a bourdon type pressure gauge coupled to a rotating potentiometer, and

(b) a flexible diaphragm whose capacitance to a fixed plate determines the frequency of an oscillator, this frequency being demodulated to give a measure of diaphragm position and, hence, pressure. A suggested circuit for the switching networks and isolation amplifiers is shown in Figure 13.

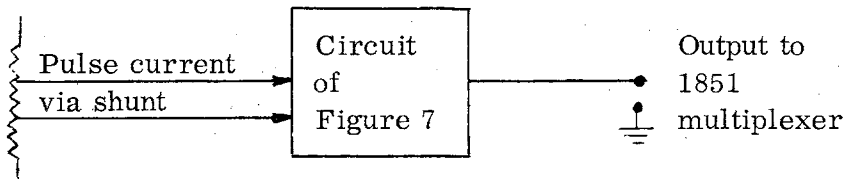
7.2.6.1 Air pressures monitored

(a) Airpad pressures; 2 only

(b) Brush actuation air tank pressures; 9 only

7.2.6.2 Signal description

Amplitude: (a) 0 - 100 mV; (b) 0-2 V



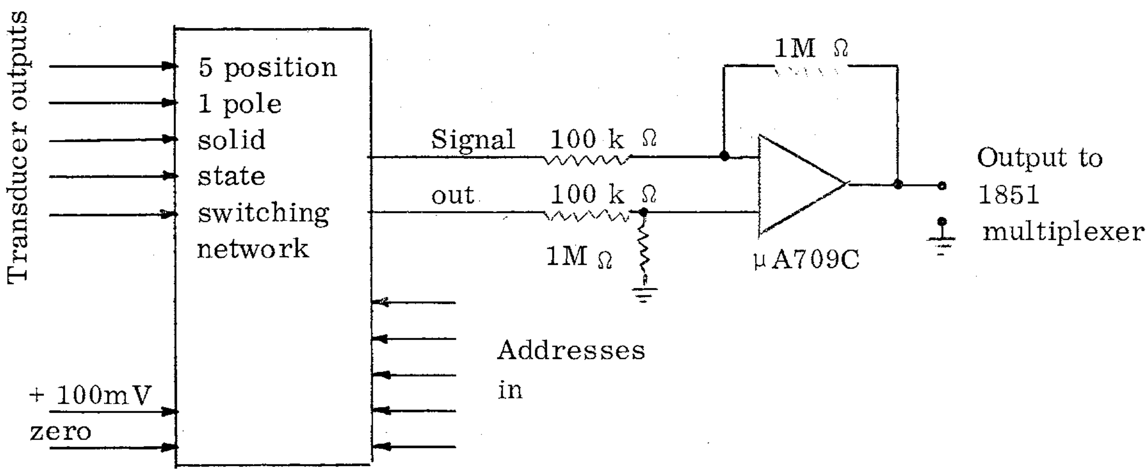


Figure 14. Pulse Current Group;
Data Acquisition Circuits

Source impedance: (a) < 100 Ω; (b) - low

Common-mode voltage: (a) ±10 V d.c. + induced noise. (b) induced noise only

Frequency components of interest: d.c. to 1 Hz.

7.2.6.3 Data logging and alarm scanning requirements

The air pressures should be logged every two minutes and alarm scanned every five seconds. An increase logging rate may be necessary during the taking of a pulse.

7.2.6.4 Comments

The limits for satisfactory operation will generally be fixed but the air pressure in the pulse brush actuation supply could be allowed to fall slightly both during and immediately after actuation.

7.2.7 Pulse Current Group

Because of the importance of the pulse current magnitude, it is measured by two independent transducers;

(a) a conventional current shunt,

(b) time integration of the rate of change in flux around the busbar, using an operational amplifier. Time integration of the current yields transferred charge and a peak detecting circuit yields peak current. A suggested circuit for a switching network and isolation amplifiers is shown in Figure 14.

7.2.7.1 Description of monitored variables

(a) Pulse current via shunt

(b) Pulse current via flux

(c) Peak current

(d) Transferred charge

7.2.7.2 Signal description

Amplitude: (a) 0 - 385 mV; (b) 0 - 45 V; (c) 0 - 100 mV; (d) 0 - 50 V.

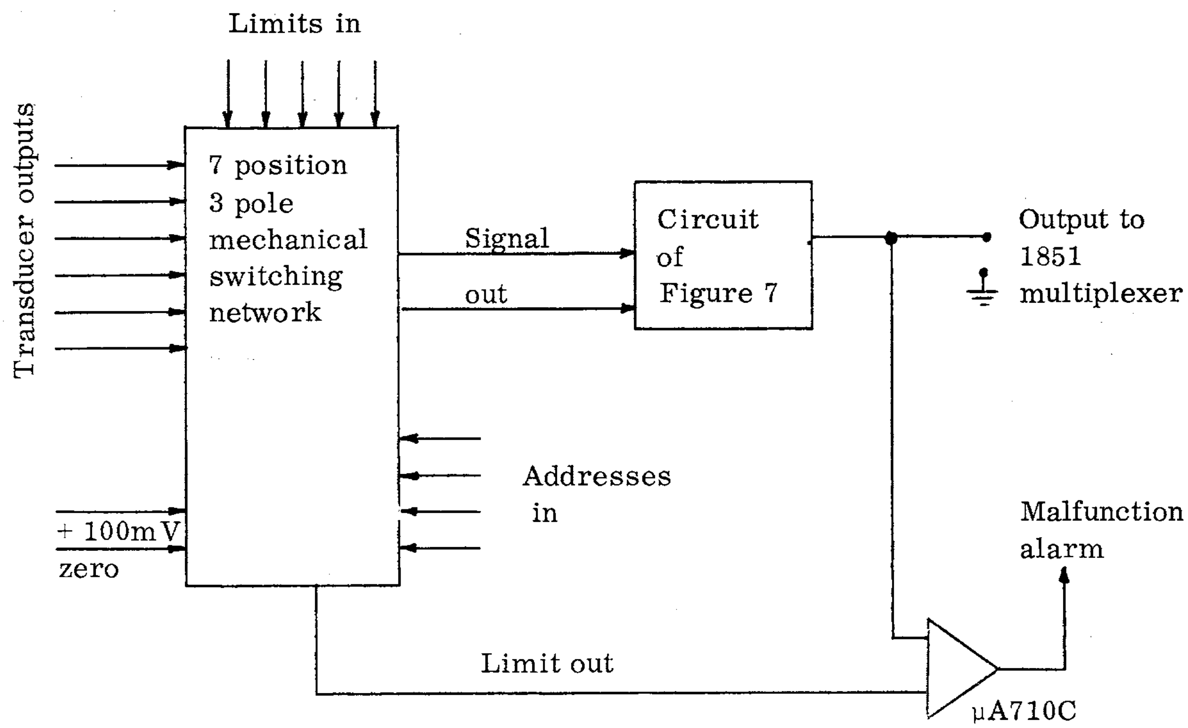


Figure 15. Magnet and Motoring Group; Data Acquisition Circuit

Source impedance: (a) very low; (b), (c), (d), - low

Common-mode voltage: (a) $\pm$ 1000 V; (b), (c), (d) - induced noise only

Frequency components of interest: (a), (b), - a.c. to 100 Hz; (c), (d) - d.c. to 1 Hz

7.2.7.3 Data logging and alarm scanning requirements

These variables need to be logged only during and after the taking of a pulse. The two representations of current should be logged at a rate of up to two hundred samples per second depending on the pulse length and rate of change. The peak current and charge transferred need to be logged only at the completion of the pulse. The current amplitude will have to be alarm scanned during the pulse but in this case the digital computer could be used.

7.2.7.4 Comments

The maximum allowable pulse current will depend on the brush and busbar configurations as well as on the experiment connected.

7.2.8 Magnet and Motoring Group

The field magnet and motoring currents and voltages will be measured by simple shunts and attenuators. The motor-generator speed in the field current supply is measured by a tacho-generator. A suggested circuit for a switching network and isolation amplifier is shown in Figure 15.

7.2.8.1 Description of monitored variables

(a) Magnet voltage

(b) Magnet current

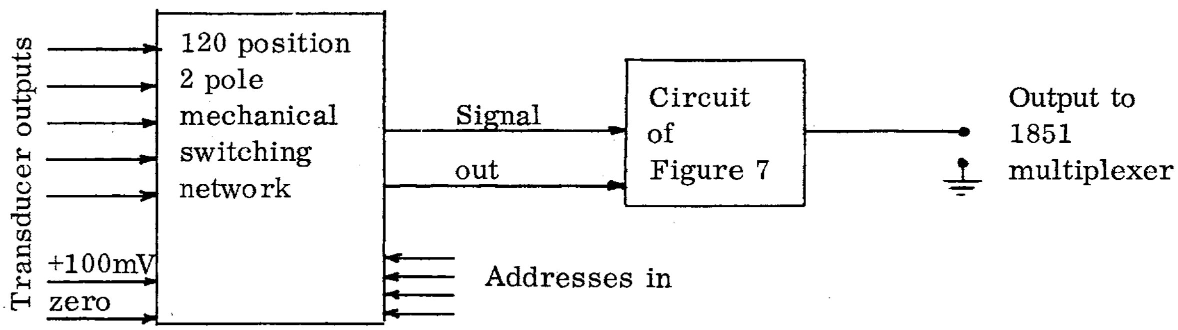
(c) Motor-generator speed

(d) Motoring voltage

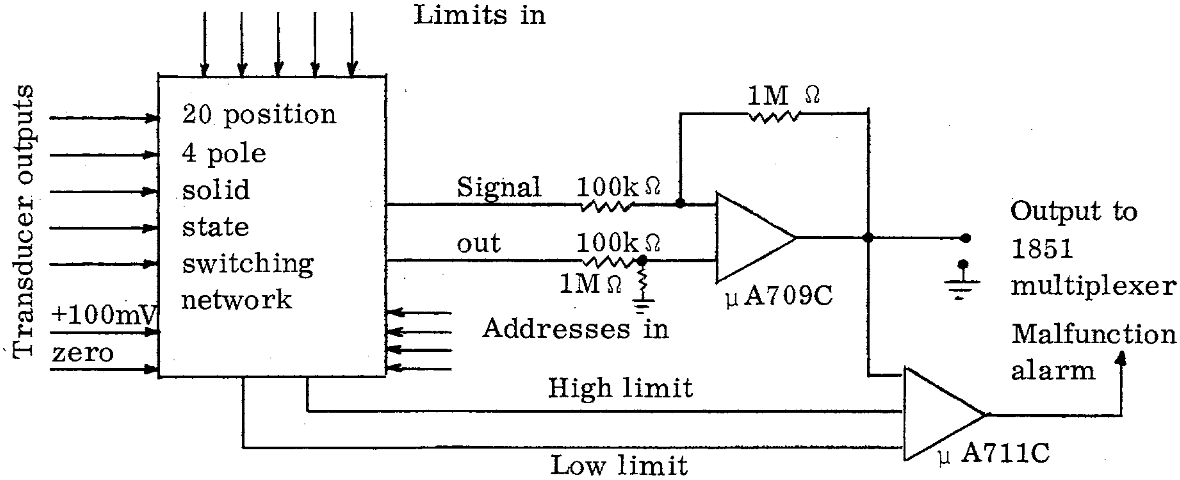
(d) Motoring current

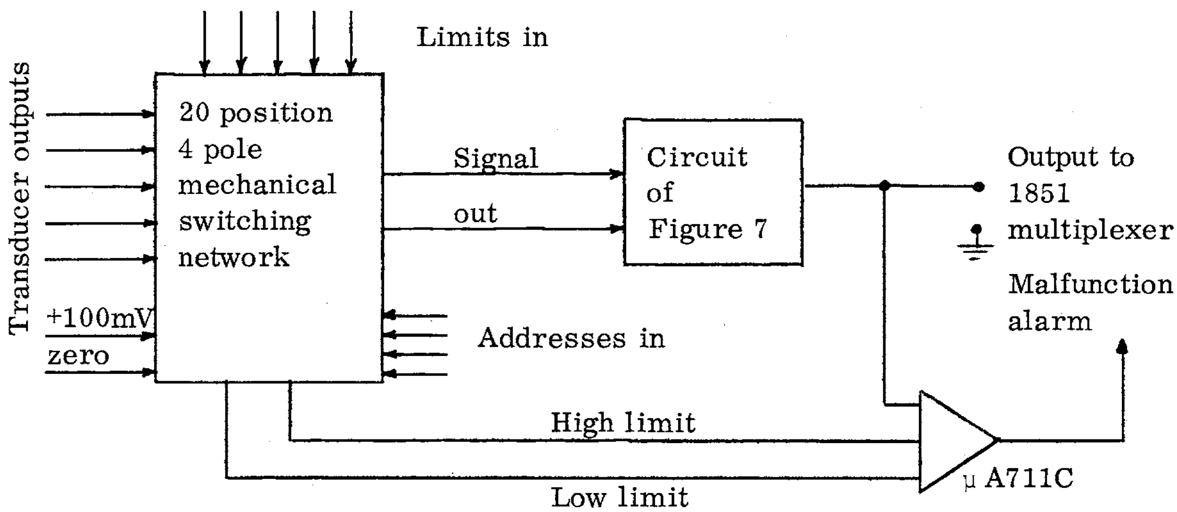
7.2.8.2 Signal description

Amplitude: (a), (d) 0 - 500 V, to be reduced by an attenuator. (b), (c), (e) 0 - 75 mV



Back-up circuit





Spare isolation amplifiers

Figure 16. Back-up and Spare Isolation Amplifiers

Source impedance: (a), (d) - will depend on attenuator. (b), (e) - very low (c) - low

Common-mode voltage: (a), (b), (d),(e) up to 500 V. (c) induced noise only

Frequency components of interest: d.c. to 1 Hz

7.2.8.3 Data logging and alarm scanning requirements

The motoring voltage and current should be logged, only during the motoring phase, once every thirty seconds. The magnet current and voltage should be logged at the same rate. The motor-generator speed needs to be logged only during the time that the synchronous motor is not connected to the mains, a rate of once every thirty seconds being sufficient unless the speed increases above the normal 750 r.p.m.

Alarm scanning should be performed, when relevant, on the motoring and field currents, together with the motor generator speed, at a rate of once every ten seconds.

7.2.8.4 Comments

The motoring and field currents will have a fixed upper allowable limit. The motor generator will have a maximum allowable speed not far in excess of its normal 750 r.p.m. Attenuators will have to be installed for the motoring and field voltages.

7.2.9 Spare Amplifiers

To obtain data from experiments being conducted in association with the H.P.G. and to obtain additional data relating to the performance of the H.P.G., several spare general purpose isolation amplifiers will be needed. An additional isolation amplifier could be used as a back-up in case of other circuit failures and for keeping a continuous watch on any variables indicating a malfunction. To perform these functions, this isolation amplifier would require a switching network which can address all transducer outputs.

The H.P.G. brush temperatures and voltage drops are examples of variables which may need to be logged by the /360 when additional data relating to brush performance is required. In acquiring this data, use can be made of the multiplexing equipment installed for the brush temperature and voltage drop monitor (a UV recorder).

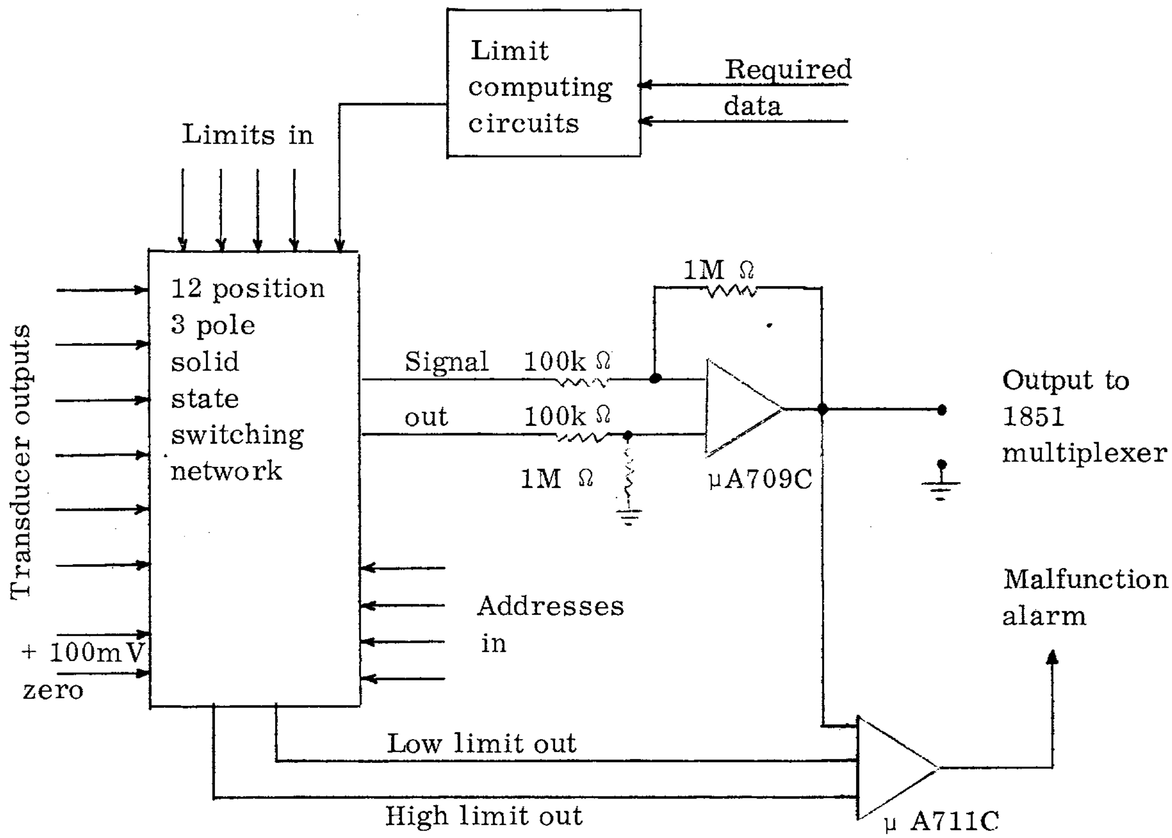


Figure 17. Miscellaneous Outputs; Data Acquisition Circuit

The number of spare isolation amplifiers used will vary from experiment to experiment but a minimum of three spare units is suggested. One of these spares would be used for the additional functions (mentioned above) to be performed for the H.P.G. A suggested circuit for the spare switching networks and isolation amplifiers is shown in Figure 16. Alarm scanning facilities may be required for the experimental variables to be logged and these are also shown.

7.2.10 Miscellaneous

A number of variables are of fairly general interest and do not belong to any one alone of the groups already considered and are considered below. The electrolytic tank position, air valve travel, pulse cam position and electrolytic tank cam position are all derived by means of moving slides on potentiometers. The rotor speeds are in this case derived by tacho-generators and the rotor accelerations are obtained by analogue differentiation of the speeds. The diesel generator output voltage (g) is measured by a moving iron (R.M.S.) meter between phases and the output frequency (h) is measured by a frequency meter. Neither of these variables is available as a d.c. voltage and suitable transducers will have to be installed. A suggested circuit for a switching network and isolation amplifier is shown in Figure 17.

7.2.10.1 Description of variables monitored

(a) Electrolytic tank position

(b) Airvalve travel

(c) Rotor speed - top rotor

(d) Rotor speed - bottom rotor

(e) Rotor acceleration - top rotor

(f) Rotor acceleration - bottom rotor

(g) Diesel generator output voltage

(h) Diesel generator output frequency

(i) H.P.G. pulse cam position

(j) Electrolytic tank cam position

7.2.10.2 Signal description

Amplitude: (a) 0 - 100 mV; (b), 0 - 70 mV; (c), (d) 0 - $\pm$ 20 V; (e), (f) 0 - $\pm$ 50 V; (i), (j) 0 - 3 V.

Source impedance: (a) - $< 100\ \Omega$; (b) $< 1\ k\Omega$; (c), (d) - low; (e), (f) - low; (i), (j) $< 1\ k\Omega$.

Common-mode voltage: (a), (b), (i), (j) $\doteqdot \pm 10$ V d.c. + induced noise. (c), (d), (e), (f) induced noise only

Frequency components of interest: d.c. to 10 Hz.

7.2.10.3 Data logging and alarm scanning requirements

Logging needs to be performed only during periods that the variables being logged are significant. For many of the above variables this will be only during the taking of a pulse. The logging rate will depend on the length of the pulse but it could be up to forty points per second. Some of the monitored variables such as rotor speeds, are of interest throughout the operation of the H.P.G. and logging will have to be performed continuously at a rate consistent with the expected rate of change for any phase of operation. Alarm scanning should be performed for all variables except the rotor accelerations, the scanning rate used varying from once every ten seconds for the rotor speeds to once every second for the pulse cam position.

7.2.10.4 Comments

The limits of satisfactory operation for the above variables will in some cases such as the diesel generator output voltage and frequency, be fixed while in other cases such as the pulse cam position, the allowable limits will depend on the particular phase of H.P.G. operation.

7.2.11 Summary of Equipment Required

The following equipment will be required for the circuits of Figures 8 to 17.

7.2.11.1 Address decoding matrices and ring counters

During normal operation of the H.P.G. and between the periods of data logging, the various switching networks will index around the inputs for the purpose of alarm scanning. This indexing could be achieved by the use of ring counters which are active only when data logging is not being performed.

When data logging is to take place the computer programs can supply the "address" of each transducer to be accessed via a digital output module and decoding matrix. Each address could cause several of the transducers to be connected via their switching network and isolation amplifier to an 1851 multiplexer terminal. The computer can access the required transducer output by sensing the appropriate 1851 terminal. Alternatively, by the use of a large decoding matrix, only one transducer would be connected to any of the 1851 terminals for each address supplied by the computer. A better approach would be to use two decoding matrices--one for supplying high speed (solid state) switching network addresses and the other for supplying low speed (mechanical) switching network addresses.

7.2.11.2 Switching networks

Solid-state and mechanical switching networks will be used. 3N87 dual emitter transistors could be used as the solid-state switches while either uniselectors (with the associated logic necessary for random addressability) or an array of relays, such as that developed by Mr. Cantor, could be used for the mechanical networks.

The switching networks required are summarised below.

Circuit	Requirement
Figure 8	12 position 2 pole solid-state, + 4 position 4 pole solid-state
Figure 9	10 position 2 pole solid-state
Figure 10	16 position 4 pole solid-state
Figure 11	10 position 3 pole mechanical
Figure 12	20 position 3 pole solid-state + 3 position 2 pole solid-state
Figure 13	13 position 4 pole solid-state
Figure 14	5 position 1 pole solid-state
Figure 15	7 position 3 pole solid-state
Figure 16	120 position 2 pole mechanical + 20 position 4 pole mechanical + 20 position 4 pole solid-state
Figure 17	12 position 3 pole solid-state

An estimated cost for these is $1,000.

7.2.11.3 Isolation amplifiers and comparators

The amplifiers and comparators used in the circuits of Figures 8 to 17 are summarised below.

Type	Quantity	Estimated cost
Circuit of Figure 17	8	\$560
Fairchild μA709C	8	80
Fairchild μA710C	7	35
Fairchild μA711C	5	90
		\$765

7.2.11.4 Power supplies

(a) $\pm$ 15 V @ 1.5A regulated

(b) $\pm$ 12 V @ 1.0A regulated

(c) 15 kC square wave, $\pm$ 20 V peak at $\pm$ 1.0A peak

An estimated cost for the above supplies is \$300.

7.2.11.5 Alarm limit computation circuits

In those cases where the alarm limits are not fixed and the alarm scanning is to be performed by discrete circuits, the alarm limits will have to be computed by analogue circuits.

An estimated cost for these circuits is \$400.

Publications by Department of Engineering Physics

No.	Author	Title	First Published	Re-issued
EP-RR 1	Hibbard, L. U.	Cementing Rotors for the Canberra Homopolar Generator	May, 1959	April, 1967
EP-RR 2	Carden, P. O.	Limitations of Rate of Rise of Pulse Current Imposed by Skin Effect in Rotors	Sept., 1962	April, 1967
EP-RR.3	Marshall, R. A.	The Design of Brushes for the Canberra Homopolar Generator	Jan., 1964	April, 1967
EP-RR 4	Marshall, R. A.	The Electrolytic Variable Resistance Test Load/Switch for the Canberra Homopolar Generator	May, 1964	April, 1967
EP-RR 5	Inall, E.K.	The Mark II Coupling and Rotor Centering Registers for the Canberra Homopolar Generator	Oct., 1964	April, 1967
EP-RR 6	Inall, E.K.	A Review of the Specifications and Design of the Mark II Oil Lubricated Thrust and Centering Bearings of the Canberra Homopolar Generator	Nov., 1964	April, 1967
EP-RR 7	Inall, E.K.	Proving Tests on the Canberra Homopolar Generator with the Two Rotors Connected in Series	Feb., 1966	April, 1967
EP-RR 8	Brady, T.W.	Notes on Speed Balance Controls on the Canberra Homopolar Generator	Mar., 1966	April, 1967
EP-RR 9	Inall, E.K.	Tests on the Canberra Homopolar Generator Arranged to Supply the 5 Megawatt Magnet	May, 1966	April, 1967

No.	Author	Title	First Published	Re-issued
EP-RR 10	Brady, T.W.	A Study of the Performance of the 1000 kW Motor Generator Set Supplying the Canberra Homopolar Generator Field	June, 1966	April, 1967
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EP-RR 12	Carden, P.O.	Mechanical Stresses in an Infinitely Long Homogeneous Bitter Solenoid with Finite External Field	Jan., 1967	
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EP-RR 15	Bydder, E.L. Liley, B.S.	On the Integration of "Boltzmann-Like" Collision Integrals	Mar.,1967	
EP-RR 16	Vance, C.F.	Simple Thyristor Circuits to Pulse-Fire Ignitrons for Capacitor Discharge	Mar.,1967	
EP-RR 17	Bydder, E.L.	On the Evaluation of Elastic and Inelastic Collision Frequencies for Hydrogenic-Like Plasmas	Sept.,1967	
EP-RR 18	Stebbens, A. Ward, H.	The Design of Brushes for the Homopolar Generator at The Australian National University	Mar.,1964	Sept., 1967

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