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An automatic sample changer for gamma spectrometry

D. J. ANDREWS

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CONTENTS

1. Introduction

Monitoring of the environment for radioactivity, especially of artificial origin, is an important aspect of the role of the Directorate of Fisheries Research of the Ministry of Agriculture, Fisheries and Food (MAFF) at Lowestoft in meeting statutory responsibilities for the control of radioactive waste discharges to the aquatic environment. This requires the collection and radiometric analysis of a large number of environmental samples. Many of these are large in volume because of the low levels of radioactivity found. These samples, which may number thousands per year, are of silt, seaweed, fish or sea water and each one must be processed both to reduce volume and increase homogeneity; the techniques that have to be employed vary with nuclide, type of sample and the amount of activity involved.

This multiplicity of samples highlights the need for some form of automatic sample changing system. The commercially-available sample changers are generally designed to cater for users whose samples are of small quantity, typically 80 mm x 20 mm tubes, and with known, usually single, isotope-content to enable a single channel integral counting system to be used. Such equipment is therefore generally unsatisfactory either for direct use or in a modified form for the MAFF radiological work which necessitated the design and building of a special sample changer at Lowestoft.

The automatic sample changer described here is suitable for use with most existing gamma spectrometry systems which utilize germanium lithium (GeLi) or sodium iodide (NaI) detectors in vertical mode, in conjunction with a pulse height analyser having auto-cycle and suitable data output facilities; it is linked to a Nuclear Data ND 6620 computer-based analysis system. It is designed for large-volume, low-activity environmental samples of various sizes up to maximum dimensions 100 mm diameter x 60 mm high.

2. Principles and description of the system

2.1 Basic design specification

The basic requirements for the initial design were:

(a) ability to handle up to eight samples at a time;

(b) acceptance of several different source geometries with a maximum expected size of 100 mm diameter x 60 mm high;

(c) operation with a range of vertical mode detectors;

(d) input and output electronics to be compatible with Nuclear Data 6620 (ND 6620) series of data analysis systems;

(e) system to offer Automatic, Manual, Manual Load and Single Sample Repeat (SSR) modes of operation;

(f) adjacent and other samples on the sample changer to have no discernible effect on the result of the sample being counted;

(g) the sample changer lead shield access aperture size to be minimal; and

(h) automatic 'abort' if the system fails.

Many ideas as to how these broad specifications could be met were discussed and evaluated before deciding on the final design shown in Figure 1.

2.2 General

The sample changer has been designed to meet all eight basic specifications and to offer maximum flexibility with regard to sample size, ease of operation and long-term reliability. Figure 1a shows the whole system comprising the changer, lead shield, detector assembly and support table. The changer (Figure 1b and c) can hold up to eight samples, each 100 mm diameter by 60 mm high at most, which can be loaded into their sample carriers by manually turning the turntable. All controls and indicators are mounted on the front panel and in the main are self-explanatory. External connections comprise 240 V AC mains supply via a three-way filtered socket on the rear panel and two control signals via BNC coaxial sockets. The overall dimensions of the sample changer are: length 0.76 m, height 0.5 m and depth 0.56 m, with a total weight of $\approx$ 50 kg. To the length must be added 0.36 m for the perspex sample guide assembly which protrudes via an aperture in the shield wall to the detector. In the system described here, the changer unit is connected to a ND 6620 computer-based data analyser.

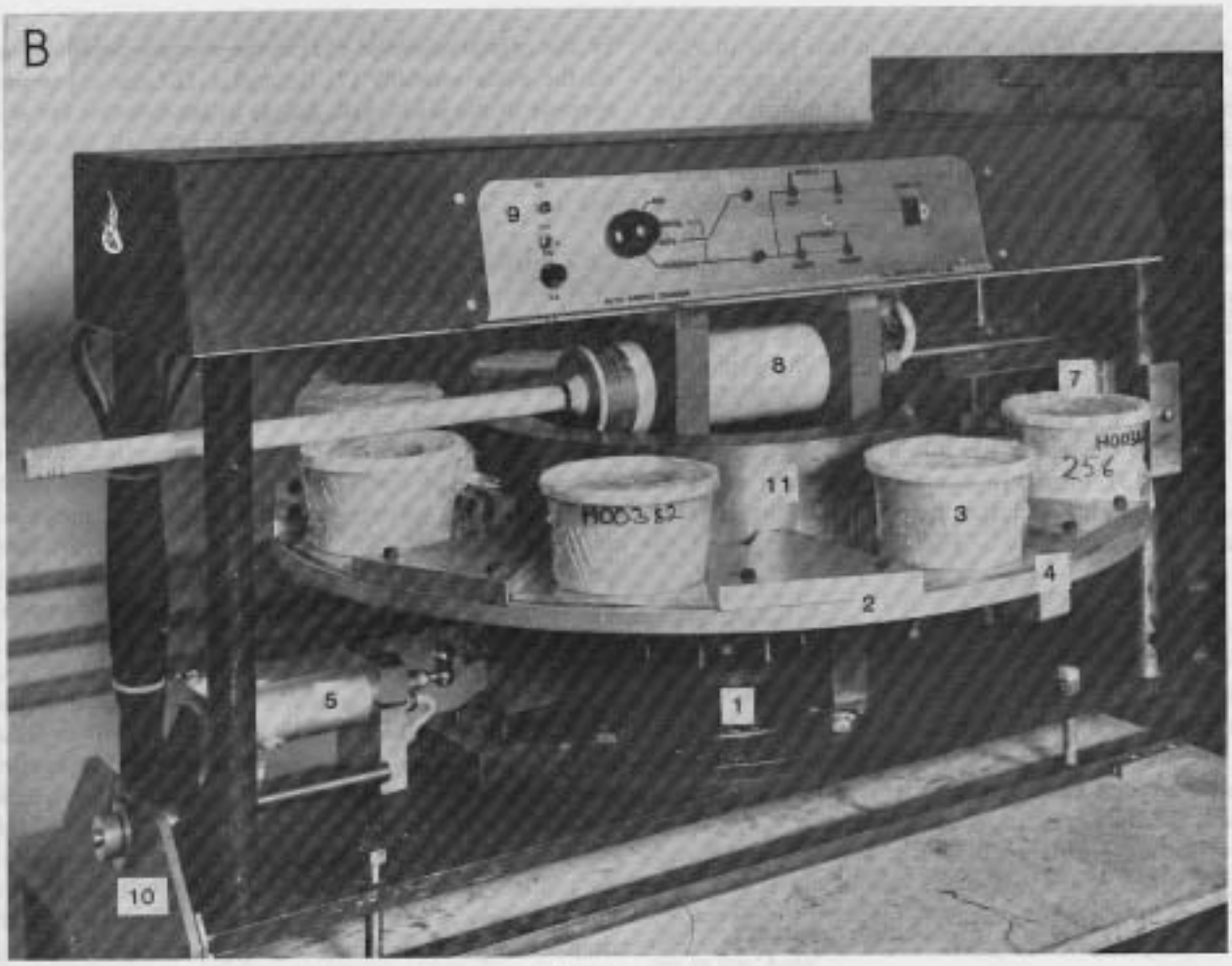
Programs have been written to sequence the system automatically through data acquire, printout and sample change modes for up to a maximum of eight samples; count time, printout format and number of samples are pre-selected by the operator. Tests are made at each change of sample to check for correct operation and to abort the program in the event of a failure being detected.

2.3 Major components

The major components of the sample changer are identified in Figure 1 which shows how the final design centres on an eight-position indexing mechanism mounted on an adjustable 12.5 mm steel base plate (1), to which is fixed a turntable (2) holding the eight samples (3) and sample carriers (4). The mechanism is turned by an electrical linear actuator (5) and locked into position on its return stroke. The sample nearest to the detector is transported to the detector face (6) within the lead shield via a perspex guide (7) by another electrical linear actuator (8). Electronic control circuitry, operating controls and indicators are housed in a unit mounted above the main assembly (9) supported by four 300 mm x 25 mm pillars located at the corners of the base plate.

Figure 1 The sample changer system, with components identified by numbers: (a) overall view of the system comprising the changer (top left), lead shield (top right) and detector assembly (lower right) (b) The changer (c) The changer alone, with lead shield removed and position of detector head indicated.

Key:
1 8-position indexing mechanism
2 Turntable
3 Samples
4 Sample carriers
5 Linear actuator
6 Detector
7 Sample guide
8 Linear actuator
9 Control unit
10 Sample changer position adjuster
11 Sample shield
12 Dewar
13 Lead shield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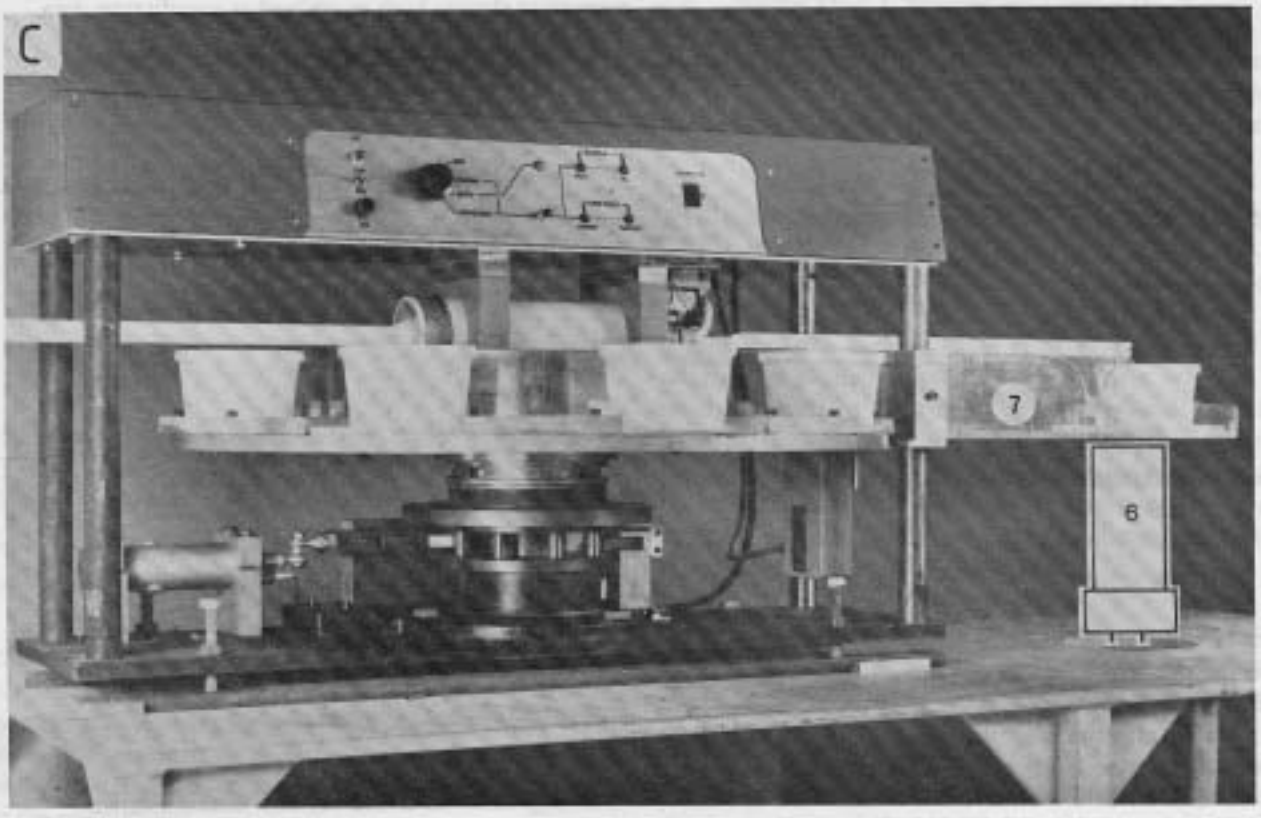
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The perspex guide (7) is constructed in two parts to allow easy removal of the detector without the need to move the sample changer itself. Positive location of the guide to the detector is effected by three adjustable roller guides bearing on the periphery of the detector. If a detector change results in a change of height, the sample changer may be correspondingly adjusted by four screws on the base plate, and its lateral position by an adjusting mechanism (10), the amount of adjustment available being sufficient to accommodate most detector assemblies. Shielding of samples other than the one being counted is effected by a cylindrical lead shield (11) mounted on the turntable. The detector is supported by the Dewar (12) containing liquid nitrogen and protrudes through a 100 mm hole in the base of the lead shield (13). Figure 1c shows the guide (7) with lead shield removed, and indicates the position of the detector by line drawing.

2.4 Geometry

Constant geometry of the sample to the detector is achieved by positively locating the sample carrier on to the detector face (Figure 1c and Figure 2). Each sample carrier is machined to form a 100 mm diameter recess which acts as a location for the largest sample size, as shown in Figure 1a and b, leaving a distance of 3 mm between sample and detector which remains constant. Various shapes and sizes of sample can be accommodated by placing different inserts into the sample carriers.

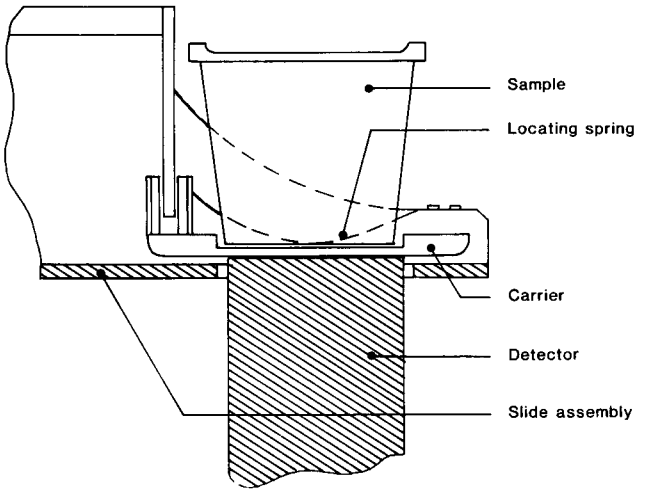


Figure 2 Sectional view of sample located over detector face.

2.5 Shielding

Figure 1a and b shows the lead shield assembly (13) mounted on the right-hand side of the support table. It measures 560 mm in each dimension and is built up in 50 mm sections with an effective wall thickness of 50 mm. Samples adjacent to the one being counted are shielded from the detector by the shield wall, and those behind are shielded by the cylindrical shield (11) in the changer. Samples pass via the guide assembly (7) through a 127 mm x 114 mm aperture in the shield wall. Access to the detector can also be achieved through a door at the front of the shield assembly.

2.6 Interfacing to ND 6620 system

The diagram of this system is given in Figure 3 and the program requirements are in Figure 4. Control signals to the sample changer are optically coupled, allowing easy interfacing to most analytical systems. The analytical system to which the sample changer is connected must be arranged so that on completion of the acquisition and printout (or storage) of data, a TRIGGER pulse is produced initiating a sample changing sequence. When the new sample is in position, a signal called BUSY is generated by the sample changer which is used to return the analysis system to the data-acquire mode. In the ND 6620 system a sixteen bit port is available comprising eight 'status' and eight 'control' bits. A 'control' bit is used to generate the sample changer TRIGGER pulse and a 'status' bit to sense the BUSY signal and to place the system into the acquire mode. Programs have been written to monitor the TRIGGER and BUSY signals and check for correct operation of the sample changer, to auto-cycle, until the eight samples on the turntable have been counted, and to abort if any failure should occur. A program for the identification of each sample changer by decoding the 'status' bit values has been written to enable the spectral data to be linked with the correct heading data and subsequently filed on hard disc for permanent storage both as raw and as quantitative data.

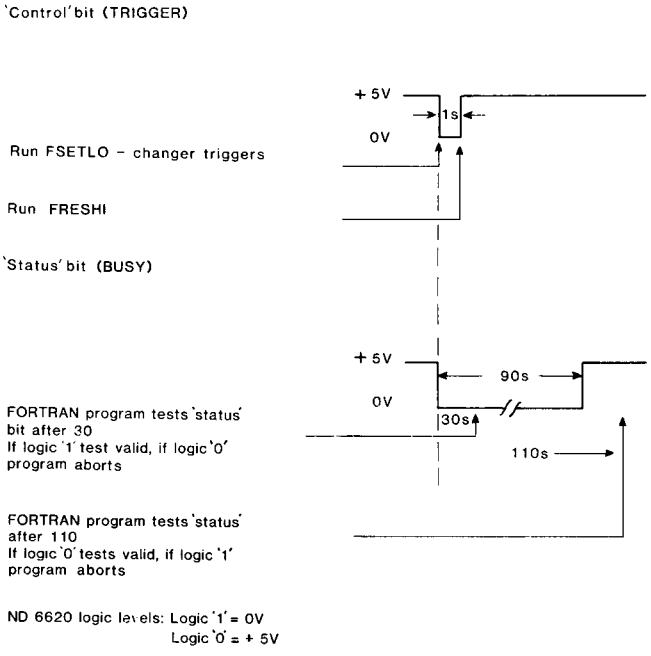
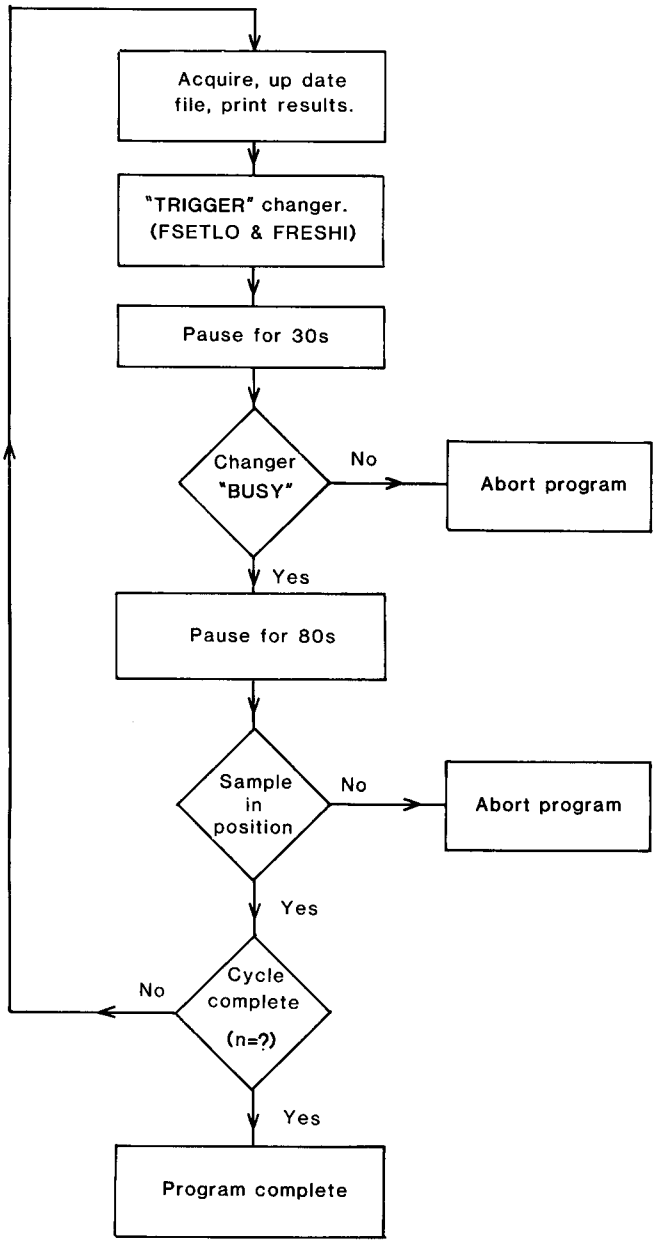


Figure 3 ND 6620 system timing diagram.



Fgure 4 ND 6620 system program flow chart.

3. Method of operation

There are two main mechanical functions:

(a) rotation of the table, and

(b) transport of the carrier and sample to the detector face.

These functions are monitored by four LED indicators on the front panel – 'Turning' 'Locked', 'Sample OUT' and 'Sample IN'. A seven-segment LED sample number indicator is also provided as an operational aid during counting which is referenced to numbers stamped on the periphery of the sample table.

The four modes of operation, 'Auto', 'Single Sample Repeat (SSR)', 'Manual' and 'Manual Load', are selected by a rotary switch on the front panel. A further LED is provided to indicate when the 'Auto' position is selected.

3.1 'Auto'

In 'Automatic', which is the normal operational mode, the changer is controlled by the ND 6620 system. The sample is retracted from the detector to the table on receipt of a TRIGGER pulse; the table indexes by one, and the next sample is transported to the detector face; the BUSY signal is initiated.

3.2 'SSR'

'SSR' allows the system to repeatedly count the same sample. The sample remains in position and the BUSY signal is initiated by the control circuitry to enable the analysis system to continue counting.

3.3 'Manual'

'Manual' enables the changer to cycle by operation of a push switch on the front panel. The sequence is initiated by the 'Manual' push button, otherwise the movements are as for 'Auto'.

3.4 'Manual Load'

When 'Manual Load' is selected the sample is retracted to the table, which may then be indexed at will by the operation of the 'Manual' push button on the front panel.

3.5 General operational procedure

Select 'Manual Load' and note that the sample is retracted to the turntable. The table may then be indexed at will and loaded with the samples to be counted, ensuring that the samples are located correctly in the carriers. When all the required positions have been filled the mode switch is momentarily turned to the 'SSR' position, thus initiating the transport of the sample to the detector face, and then the 'Auto' position is selected. At this stage the 'Auto', 'Locked' and 'Sample IN' indicators are illuminated and the sample changer is ready for operation.

The 'Auto' cycle program in the ND 6620 computer system is called up and the sample data entered; for example, count time, sample description, number of samples, sample changer-number.

Having completed the programming requirements, the system is now ready to acquire data. Counting will continue

until all samples have been counted and data stored. The 'SSR' mode may be used in conjunction with the 'Auto' cycle program for repetitive counting of the same sample.

4. Circuit description

The overall plan is given in Figure 5. The full circuit diagram for the system is shown in Figure 6.

The linear actuators are 240 V AC devices controlled by solid-state relays and internal and external microswitches, while the main control circuitry comprises mainly CMOS logic.

AC power to the unit is supplied via a line filter to reduce transmitted or received transient interference. A regulated +12 V supply is provided by the circuit shown in Figure 7, using a 7812 regulator, with raw filtering provided by C1, R1 and C2, giving a ripple of ≈ 10 mV at 200 mA. The total mean load of the sample changer electronics is ≈ 150 mA at 12 V. Two opto-isolators are included for the TRIGGER and BUSY signals which are supplied with 5 V derived from the 12 V line via R8 and D1 giving compatibility.

Both linear actuators (Figure 6) are intended for very low duty cycles. To prevent them running hot, series current limiting resistors have been included to reduce the current to ≈ 250 mA for the 'sample' actuator and ≈ 90 mA for the 'rotate' actuator, but internal thermal cutouts are also fitted. Auto-test runs have been carried out for several days at a frequency of one sample change every 2 min without the occurrence of overheating. Torque, although reduced, is sufficient for adequate operation and also enables either actuator to be stalled without harm in the event of any physical obstruction occurring. Switching transients are also reduced.

With reference to Figure 6, the sequence of events that brings about a change of sample is as follows. First the 'sample' actuator retracts and removes the monitored sample from the detector location to the table; microswitch 2 (MS2) senses when the arm is fully retracted and initiates the operation of the 'rotate' actuator. The 'rotate' actuator then extends and rotates the table, indexing by one. When the 'rotate' actuator is fully extended microswitch 4 (MS4) is operated causing the actuator to fully retract, which locks the mechanism and also operates microswitch 5 (MS5). This initiates the 'sample' actuator after a short delay of ≈ 200 ms and positions a new sample on the detector. When the sample is in position, microswitch 1 (MS1) causes the BUSY signal to return high.

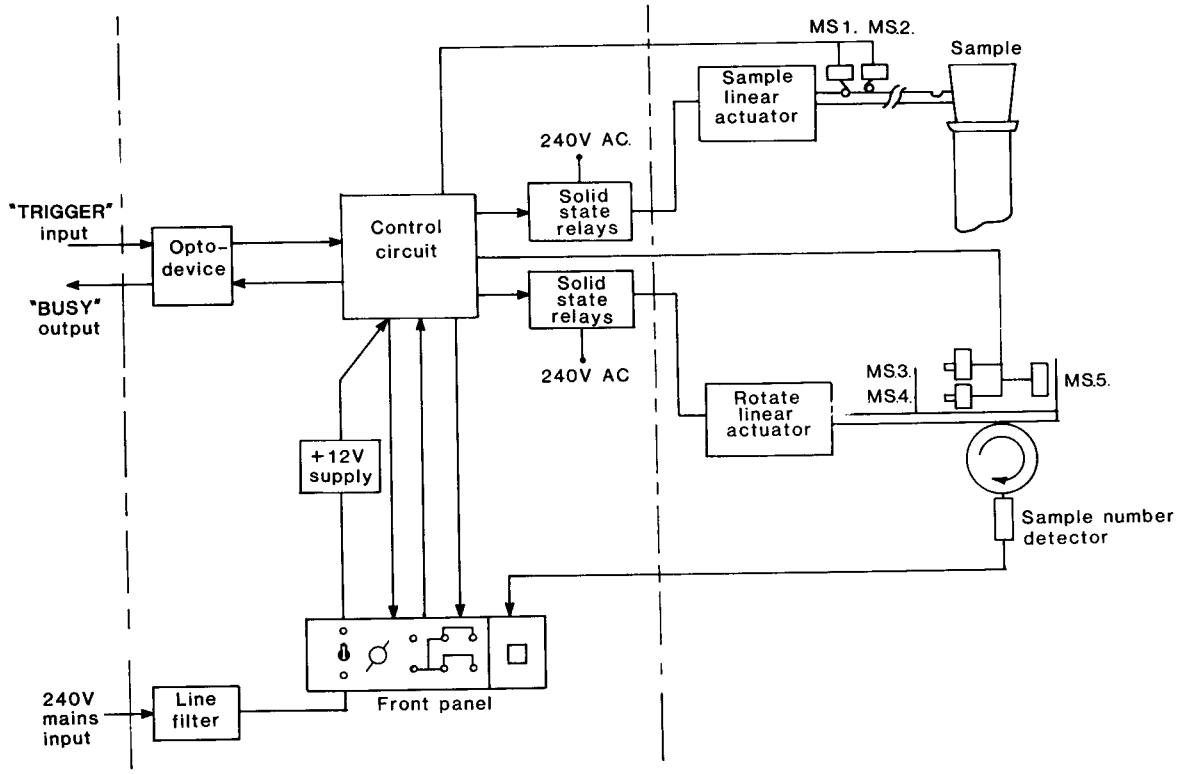


Figure 5 Block diagram of main components.

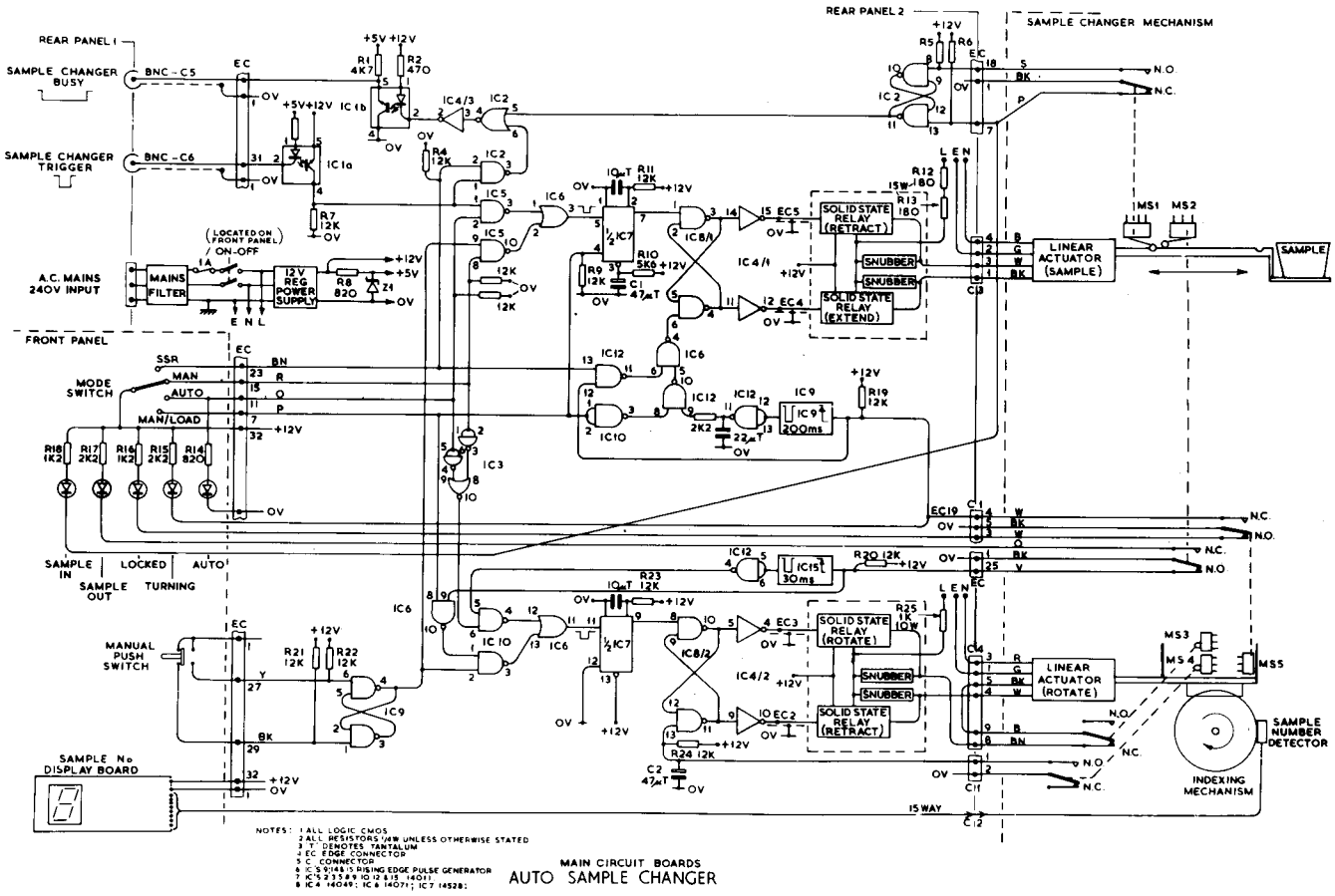
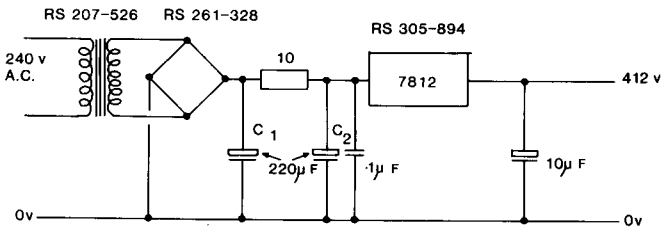


Figure 6 Circuit diagram of electronics. Mechanical devices are on the right-hand side, the main circuit board and solid-state relay boards in the centre, and the rear and front panels on the left-hand side.



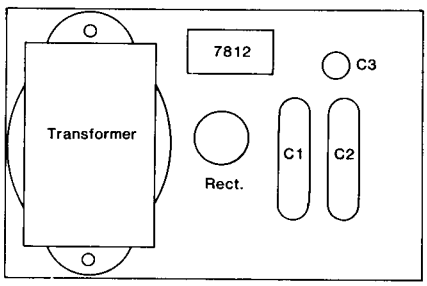


Figure 7 Power supply.

4.1 Operation of 'sample' actuator and opto-isolator signals

Again with reference to Figure 6, the normal operating position for the 'sample' actuator is in the fully extended position with the sample located on the detector face, MS1 relaxed, MS2 operated. The timing diagram is in Figure 8.

Control of the 'sample' actuator is achieved by a solid state relay via drivers IC4/1 and latch IC8/1 allowing either a 'retract' or 'extend' command. A 'retract' pulse is generated by IC7; this monostable performs several functions in that it generates a constant length trigger pulse (200 ms) thereby reducing the possibility of transient pulses retracting the sample, it also allows triggering from two sources (pins 4 and 5 of IC7), and it is held reset during switch-on or power interruptions (pin 3, C1/R10) causing the actuator to extend or remain extended. A 'retract' command can be generated by a TRIGGER pulse via opto-isolator IC 1a, NAND gate IC5 and pin 1 of IC6 ('Auto'), or by the 'Manual' push-switch via IC9 latch, IC5 and pin 2 of IC6 ('Manual') – both feeding pin 5 of IC7 – or by the mode switch in 'Manual Load' position forcing pin 4 of IC7 high.

The source of a sample actuator extension command can be initiated by the mode switch being in 'SSR', 'Manual' or 'Auto'. In 'SSR' pin 13 of IC12 goes high and, as long as a 'rotate' operation is not in progress, pin 12 of IC12 will also be high so that pin 11 goes low, triggering latch IC8/1 and operating the 'extend' solid state relay via IC4/1. In

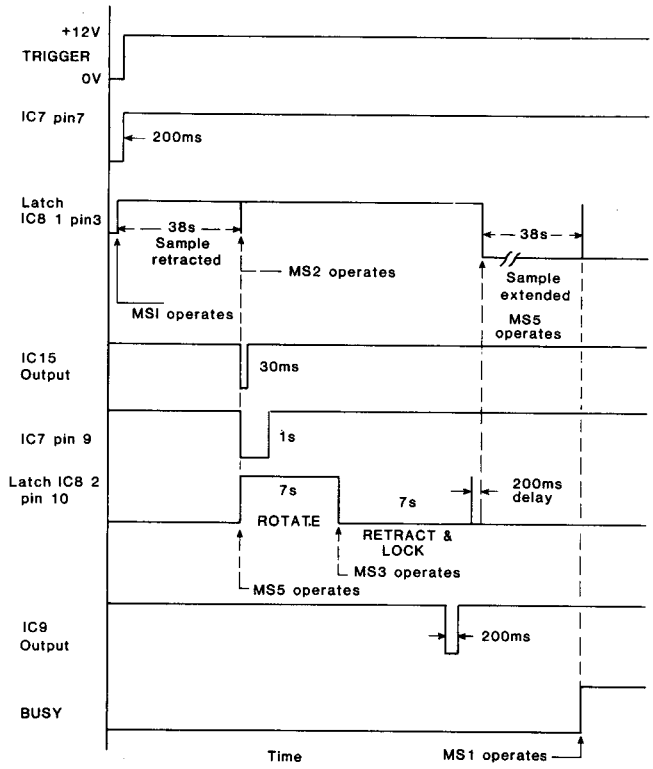


Figure 8 Timing diagram, in 'Auto' mode.

'Manual' or 'Auto' IC8/1 may also be triggered by MS5 on the completion of a 'rotate' operation, causing the input to IC9 to go high and so producing a negative pulse output fed via IC12 and IC6, again operating latch IC8/1 and the 'extend' solid state relay. This pulse can be inhibited by the mode switch when in 'Manual Load' position putting a low on pin 8 of IC12 via IC10. IC9 is a rising edge pulse generator for positive-going inputs only (see Figure 9).

If the changer is in operation, MS1 is operated, placing a low on pin 2 of latch IC2 which causes the BUSY signal to go low via pin 5 of IC2, IC4/3 and opto-isolator IC16. When the sample is in position, MS1 is operated by a detent in the actuator shaft causing a low to be placed on pin 13 of latch IC2 and putting a high to the input of IC2 pin 5 making the BUSY signal return to high. In 'SSR' mode, the BUSY signal is generated by the TRIGGER pulse via IC2 pin 1. Microswitch 2 (MS2) is used to initiate the generation of the trigger pulse for the 'rotate' operation and is actuated by a detent in the actuator shaft when the sample is fully retracted.

4.2 Operation of the 'rotate' actuator

As shown in Figure 6, the 'rotate' operation is completely self-contained in that a single pulse, from IC7 via latch IC8/2, causes the actuator to extend and rotate the table by one sample, then to retract and lock the indexing mechanism. There are three microswitches associated with its operation, MS3, MS4 and MS5. MS3 controls the mechanical limit to the actuator's extension; it has been used instead of the internal microswitch to enable the limit to be set as determined by correct operation of the indexing mechanism. MS4 initiates the 'retract' operation and is adjusted to operate fractionally after MS3. MS5 initiates the extend command for the 'sample' actuator and is adjusted to operate when the table has locked into position.

The turntable circuit can be triggered from two sources: first, when the sample is retracted, by MS2 asserting input to IC15, leading to generation of a negative pulse fed via IC10 and IC6 in either 'Manual' or 'Auto' modes; and secondly, by the manual push switch via latch IC9 and IC10 pin 2, when mode switch is in 'Manual Load' only and the sample actuator is not in operation.

4.3 ND 6620 interface signals

A sixteen bit output port is provided on the ND 6620 consisting of eight 'status' and eight 'control' bits, all of which can be individually sensed and controlled respectively. Logic levels on the ND 6620 (see Figures 3 and 4) are: logic '1' = 0 V, logic '0' = +5 V. At reset, all sixteen lines are held at +5 V. A control bit output is used for the sample changer TRIGGER signal, activated by FORTRAN subroutines FSETLO and FRESHI, following data-acquire and printout modes. Having triggered the sample changer, the BUSY signal immediately goes to 0 V (logic '1') for the 90 s duration of the sample changing operation. During this period two tests are made on the 'status' bit input to which the BUSY signal is connected: at TRIGGER + 30 s, which looks for a logic '1' to check that the changer is operating, and at TRIGGER + 110 s, which looks for a logic '0' to check that the operation has been successfully completed. If both tests are successful the system will then return to the data-acquire mode. If either test fails, the program is aborted. This sequence of events continues until such time as the selected number of sample changes and acquire cycles have been completed.

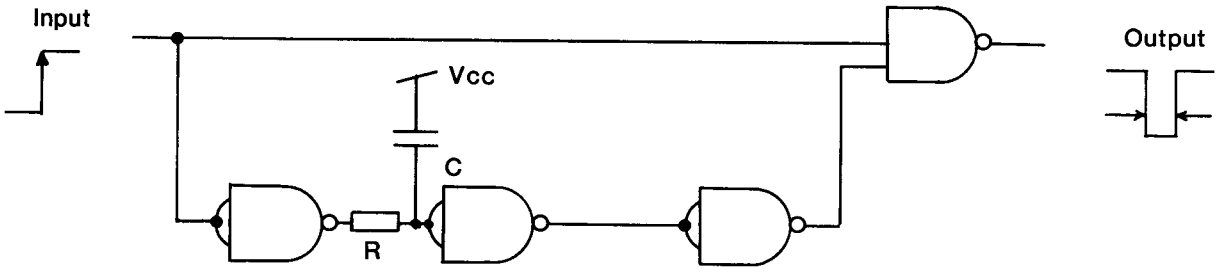


Figure 9 Rising edge pulse generator.

4.4 Miscellaneous items

Again with reference to Figure 6, the front panel LED indicators are connected to the 12 V line, with the exception of the 'Auto' LED, via individual current limiting resistors R14-R18, and therefore require a low for operation.

'Auto' (amber) is connected directly to the 'Auto' position on the mode switch. The 'Turning' (red) and 'Locked' (green) LEDs are connected to MS5 and therefore indicate either condition. 'Sample OUT' (red) is connected to NC contact of MS2 and 'Sample IN' (green) connects to NC contact of MS1.

The sample number indicator (Figure 10) is a standard 1.5 mm 7-segment common cathode LED driven by a 14511B binary to a 7-segment LED driver. Four identical circuits comprising opto-switch and transistor (2N 3904) are connected to the four BCD inputs on the 14511B. The four opto-switches are housed in a small unit mounted physically near the underside of the turntable and sense one of eight binary coded areas corresponding to the denary numbers 0-8. The remaining components are mounted on a small circuit board located on the front panel. A multi-way cable interconnects the two units, and is supplied from the +12 V line. Some adjustment of the detector unit may be required during initial installation and in the event of the table having to be moved for any reason.

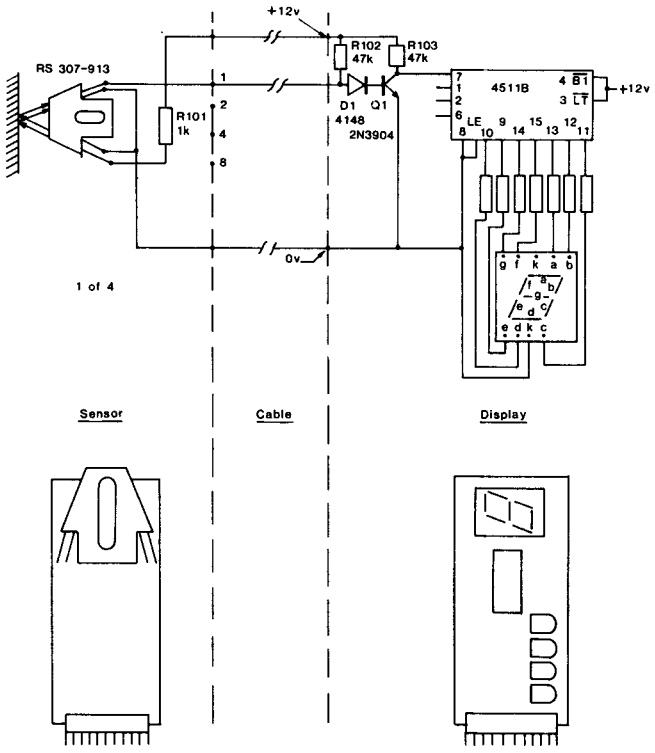


Figure 10 Sample number counter circuit and layout

5. Maintenance

Little maintenance of the unit should be required except for periodic oiling of the indexing mechanism and actuator shafts. Some adjustment of MS4 or MS5 for correct operation, may be necessary after component wear. The table slide and carriers should be kept free of dust, etc.

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