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**A MICROPROCESSOR SEQUENCER
FOR THE UK T5 ION THRUSTER
AND POWER CONDITIONER UNIT.**

by

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J.A./Williams

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Farnborough, Hants

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A MICROPROCESSOR SEQUENCER FOR THE UK T5 ION THRUSTER AND POWER CONDITIONER UNIT

by

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SUMMARY

The Report describes a programme of work in which a previously existing hard-wired logic sequencer for the UK T5 10cm diameter ion thruster was replaced by a sequence generated by an Intel 8080A microprocessor. Details of the new system are given, together with background information relating to sequence requirements that arise from the thruster's electrical power needs. Electrical features of the ion thruster are described where relevant to the switch-on procedure.

A second, minor, part of the Report proposes a logical extension to the use of microprocessors in the ion thruster power conditioner context. Such use would realize much more fully the potential of these devices, and would result in a reduction of the mass and volume of the power conditioner and increase its reliability.

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LIST OF CONTENTS

	<u>Page</u>
1 INTRODUCTION	3
2 SEQUENCE AND MONITORING	4
2.1 Functional purpose of the PCU	4
2.2 The start-up sequence	6
2.3 Microprocessor monitoring of thruster performance	8
3 MICROPROCESSOR - PCU HARDWARE AND TESTING FACILITY	9
3.1 Microprocessor - PCU interfaces and peripherals	9
3.2 Testing facilities	9
4 PROGRAM DETAILS	11
4.1 Microprocessor - PCU - thruster; integration	11
5 EXTENSION OF THE ROLE OF THE MICROPROCESSOR	13
6 CONCLUSIONS	14
Appendix Sequence and surveillance flowchart and DELAY loop	15
References	17
Illustrations	Figures 1-4
	Figures A1-A2
Report documentation page	inside back cover

INTRODUCTION

The UK T5 10cm diameter mercury ion thruster^{3,5}, is a somewhat complex device in electrical terms, requiring a power conditioner comprised of some 14 distinct power supply modules to operate it. Such complexity is typical of this type of thruster, however the substantial power supply mass is more than offset, during long life missions, by the low mass of mercury propellant required. This is, of course, due to the high specific impulse of ion thrusters compared with chemically fuelled propulsion devices. North-south station-keeping of communications spacecraft is one example of a mission that can benefit enormously from the introduction of ion propulsion. These aspects are adequately dealt with elsewhere^{1,2} as are the design details and current design status of the T5 thruster itself³⁻⁵.

This Report is mainly concerned with describing in some detail the design of a microprocessor-based sequencer which has replaced an earlier version which used hard-wired logic⁹. The description includes some details of a short integration exercise that was carried out in order to demonstrate compatibility between the new sequencer, a slightly modified power conditioner unit (PCU), and the T5 ion thruster. Also included are certain relevant details of electrical features of the ion thruster test facility that exists at RAE.

The second part of the Report briefly discusses the possibility of further extending the microprocessor role in order to achieve a major reduction in PCU component count. Such a reduction would be brought about by utilising much more fully the ability of a properly programmed microprocessor to carry out complex switching functions, and should enable, in many cases, a single module to accomplish tasks previously requiring two. Indeed, in one case a three function module can be almost entirely eliminated.

In order to give appropriate background information, and thus to clarify this discussion, a comprehensive description of the functional purposes of the PCU is given in section 2.1. Here, attention is paid to the various supply categories, and to the order in which they must be energised during a thruster start-up sequence.

The chosen microprocessor was the Intel 8080A. This choice was made because the 8 data-bits available were quite adequate for the task, and the type was proven and is widely used. Of some importance was the fact that the sequence program developers, MSDS Limited, had expertise with this type. In any case, the choice of microprocessor is not too important at this stage since the PCU could

easily be adapted later on to any such device that may be space qualified, or possess some other acceptable qualification.

The current status of the work is that the change-over from hard-wired logic to the microprocessor based sequence has been achieved, and the new sequencer will start-up a T5 thruster fully automatically in a time of approximately 11 minutes, the thruster is then fully operating in a stable manner and is delivering a beam current corresponding to a thrust of 10 mN. At this stage, several important thruster operating parameters are under surveillance, and a built-in capability exists for microprocessor controlled remedial action should certain conditions of thruster malfunction occur.

2 SEQUENCE AND MONITORING

This section gives details of the T5 thruster start-up sequence. It is divided into three sub-sections. The first gives a brief description of the ways in which the thruster uses electrical power, the second presents a sequence table which details the order in which power is applied during start-up, and the third describes the reasons for microprocessor surveillance of an operating thruster and should aid in the understanding of the flowchart contained in the Appendix.

2.1 Functional purpose of the PCU

It is convenient for clarification of the purpose of a typical ion thruster start-up sequence, to place the various power modules of the PCU into three functional categories. These are:

Category 1. Power supplies for resistive heating elements. These, in general, are activated early in the sequence in order to raise component temperatures to operating levels before other supplies are activated. Some loads are constant with time, whereas others vary strongly with temperature and therefore with time.

Category 2. Power supplies for the generation of stable discharge arcs. These are required for the ionisation of mercury vapour in the thruster discharge chamber, and for space-charge neutralisation of the ion beam downstream of the ion extraction grid system. Fig 1 shows the T5 ion thruster and illustrates the main component parts and systems under discussion. The microprocessor system and PCU modules are illustrated schematically in Fig 2.

Category 3. Power supplies required to generate a high velocity ion beam by accelerating and focussing mercury ions through the grid holes to produce thrust. These are the last in the sequence to be activated.

Returning to category 1, resistive heaters are used to convert liquid mercury into vapour in the discharge, main, and neutraliser vaporisers and it is advantageous to initially apply to them a high power level, relatively speaking, in order to raise their temperatures rapidly toward operating levels.

Once in the vicinity of the operating region power must be reduced. Finally, when the thruster has reached an operating state, that is, producing thrust, the vaporisers are placed under analogue closed loop control. In this condition flow is regulated by appropriate, thruster generated error signals which constrain it to function at, or very near, its optimum operating point. Since extreme accuracy is not required, simple control loops will and do suffice.

These high, normal, and closed loop modes of operation are achieved by having a two parallel bit output between the microprocessor and each vaporiser power source as indicated in Fig 2.

Resistive heaters are also used to raise the temperatures of the discharge chamber and neutraliser hollow cathodes, see Fig 1, to around the 1000°C levels required for them to emit the electrons necessary for the mercury ionisation and beam neutralisation processes. Their tungsten heaters undergo a seven-fold change of resistance between their cold (pre-start) and hot (arc strike) states. Because of this, and also to minimise thermal shock to the cathode as it heats up, it is desirable to program the application of ac heater power by means of many small steps so that the increase of power and of temperature is smooth during the heat up phase. The hollow cathodes used have not demonstrated fragility or unreliability during severe thermal cycling tests⁶, but gentle treatment is nevertheless, considered to be prudent since it must aid reliability. Fig 3 shows ideal and step characteristics of heater power against time for both neutraliser and discharge chamber cathodes. Satisfactory performance was provided by supplying, from the microprocessor, four parallel bits into a D/A converter thus giving a capability of 16 power levels. Once a discharge anode current is established, the heater power supply is turned off by microprocessor action as a result of a signal from an anode current sensor. An operating cathode is self-heated by ion bombardment of its tip, so that resistive heating is unnecessary and, indeed, is undesirable once the arc is established.

The last members of the heater group can be classed as auxiliary heaters. These require only simple on/off control, and are necessary in order to warm certain thruster regions to prevent condensation of mercury vapour during the start-up phase. Condensation is not a problem once a thruster has reached

operating temperature since there is then ample waste heat generated. During the integration exercise this, non-critical, power was obtained from manually switched laboratory supplies although appropriate switching signals were available at the microprocessor output ports. The Report therefore treats these supplies as though they were activated as part of the automatic sequence.

Referring now to category 2 power supplies. The discharge chamber ionising arc is initially operated deliberately at a low value of anode current. The discharge chamber magnetic field current is also set to a low value. This is done because later in the sequence, when the high voltage beam forming supplies of category 3 are activated, transients of substantial magnitude can occur. A low level of discharge anode current and magnetic field reduces the ion density in the discharge chamber with the result that these transients are softened. Following the establishment of a stable ion beam, which may take many milliseconds, the discharge anode current and magnetic field current are raised to their normal operating values. The 'low' and 'normal' states are enabled by two parallel bits to each supply thus providing two values of their constant current reference levels.

In general, Fig 2 indicates the connections between the thruster, the PCU, and the microprocessor. For clarity, only a few of the connection paths are shown. The feedback of thruster status signals, such as discharge anode current 'normal' is indicated; these signals are fed into the microprocessor input ports.

2.2 The start-up sequence

The thruster start-up sequence, which is partly a function of time and partly of thruster event, is indicated in Table 1 and also in the flowchart of Fig A1. These show that following the application of power to the various heaters, the sequence waits until (normally) the neutraliser arc has struck before continuing. Later, the sequence waits until the ionising arc in the discharge chamber is established before activating the high voltage supplies that raise the potential of the discharge plasma and extract the high velocity ion beam. Following the establishment of a beam (and therefore thrust), the three analogue control loops are closed. These stabilise beam current, discharge voltage and neutralisation conditions by using appropriate error signals to modify the vapour flow from the appropriate vaporisers (by controlling their heater currents). The primary purpose of the closed loops is to maintain thruster performance substantially constant against long term parameter changes resulting from variations in component characteristics. In general these variations will take place over periods of several thousands of hours of thruster running time, although more rapid

changes must also be catered for, such as those due to alteration of solar radiation flux with orbital position.

Table 1 is thus a brief statement of the sequence, showing a start-up timing pattern appropriate to the achievement of thrust in typically, 11-12 minutes. Further background information on the philosophy of thruster start-up may be found in Refs 5 and 7. Further detail relevant to the start sequence is presented in the Appendix.

Table 1

Time (minutes)	Parameter or operation	Parameter mnemonic (see Appendix)	Switching details
0	Backplate heater	BP	ON
	Cathode isolator and main isolator pre-heaters	PH	ON, high
	Neutraliser keeper	NK	ON
	Discharge magnetic field	DM	ON, low
	Neutraliser bias	NB	ON
1½	Neutraliser cathode heater	NC	ON, 1st ramp step
2	Discharge cathode heater	DC	ON, 1st ramp step
6	Discharge vaporiser heater	DV	ON, high
7	Neutraliser vaporiser heater	NV	ON, high
T_N (~8½)	Neutraliser discharge initiates		NC - OFF, NV - normal DK - ON, DA - ON, low
T_D (~9½)	Main discharge initiates (Typically the neutraliser will strike at 8½ min and the main discharge at 9½ min.)		DC - OFF, BP - OFF, DV - normal MV - normal, PH - normal
9½	Call 'Help' if neutraliser not struck		
10½	Call 'Help' if main discharge not struck		
$T_D + 1*$	Beam (+900 V),	BM	ON
$T_D + 1 +$	Accelerator grid (-300 V), 90 ms after BM	AG	ON
$T_D + 1½$	Discharge chamber to normal	DA	} Normal
$T_D + 1½$	run settings of field and anode current	DM	
$T_D + 1½$	Initial normality check of beam and accelerator currents	BM AG	
$T_D + 1½$	20 ms after initial normality check close analogue control loops.	DV MV NV	} Close loops
	Then, continuous normality checks of beam and accelerator currents	BM AG	

* These timings are onward from main discharge initiation, T_D .

2.3 Microprocessor monitoring of thruster performance

A normally operating thruster is continuously monitored by interrogative loops which are a feature of the microprocessor program. These monitor beam current (a direct indication of thrust level), and accelerator grid current, which is normally about 0.3% of beam current. Should either of these become abnormally high (by reference to limits at present set by comparators) remedial action is taken by the microprocessor. This action results in a large reduction in the beam and accelerator power supply capability, a reversion from closed to open (analogue) loop control of the vaporiser heater currents and in a return of the ionising and magnetising currents to lower levels. Following a pause, current and power levels are restored to normal in a defined manner. This cycle of events is known as the short recycle (SR) loop. The main reason for such action is to combat a possible condition of thruster malfunction known as grid arc breakdown. This phenomenon is thought to be due to the occasional appearance^{8,13} of metal flakes or whiskers between the closely spaced ion accelerating grids. The resultant arc vaporises away this contaminating material so that short recycling provides a self-healing action. Life tests on UK thrusters having grid assemblies similar to that of T5 found no evidence of inter-grid arcs or transients of a magnitude or duration likely to cause grid damage⁴. This evidence is supported by other experimenters testing electron bombardment thrusters having ion extractor grid systems basically similar to the UK T4, T5 types¹¹. However, in other types of thruster such arcs are seen frequently, as many as 20 per hour being reported¹². Certainly arc breakdown must be considered a possibility and the SR loop is considered to be a prudent precaution. An additional safety feature is the short-circuit protection incorporated into the PCU⁹.

In the unlikely event of an abnormality that would result in a low beam current, its detection by microprocessor surveillance will cause all thruster power supplies to be deactivated, that is, the thruster is shut down. Following a substantial pause to enable thruster components to cool, a normal start-up procedure is followed. This shut-down and restart action is known as the long recycle (LR) loop.

Section 2, then, has detailed the needs of the UK T5 thruster for electrical power, and also the sequence and surveillance functions to be carried out by the microprocessor.

3 MICROPROCESSOR - PCU HARDWARE AND TESTING FACILITY

3.1 Microprocessor - PCU interfaces and peripherals

The PCU power modules⁹ are transistor operated dc-dc or dc-ac converters and all operate in pulse-width modulated (PWM) mode. The inputs will accommodate both analogue and logic signals. The present bread-board prototype requires the following power sources, +56, +12, -12, +5 and -5 volts including the supplies needed to operate the microprocessor. The main power source for all PCU modules, excepting the three-vaporiser module, is +56 volts; the latter uses +12 volts. A description of the main features of the PCU will be found in Ref 9. Since logic compatible inputs were already present in the original design, PCU-microprocessor compatibility was achieved by relatively minor modifications, mostly to satisfy the specific requirements of the new, more complicated, sequence. Thus, the old system laid the foundations for the new.

This new design required several modifications to the PCU in order to command both 'low' and 'normal' settings for discharge anode current and discharge magnetic field current, and to command 'high', 'normal' and closed loop conditions for the three vaporisers. Finally, two D/A converters were used to convert the discharge hollow cathode and neutraliser heater power commands which were available as binary 4 bit words at the microprocessor output ports, to an analogue voltage demand for an appropriate power supply pulse width.

To achieve its sequence and surveillance role the basic Intel 8080A microprocessor required memory in the form of two, 256×4 bits read/write memories (RAM) for use as work-space and stack, and four, 256×8 bits erasable programmable read only memories (ePROM) in which to store the program.

3.2 Testing facilities

The bread-board microprocessor and PCU console is shown in Fig 4. Briefly, the total electronics support system for the ion thruster at RAE consists of the following;

(1) Intel 8080A microprocessor together with its present ePROM and RAM memories Input and Output ports etc.

(2) A test and control unit and display panel for program checking purposes. These together with three octal thumb-wheel switches permit temporary, short programs to be written into RAM. Facilities also exist for feeding in programs stored on paper tape, for direct memory access (DMA), and for manual single stepping of the program.

(3) A program test unit. This connects, in place of the PCU, to the microprocessor input and output ports, and enables program checks to be carried out by observation of the binary indications given by arrays of LEDs.

(4) A manual/auto changeover facility. This allows control of the PCU to be diverted from automatic to manual. Associated with the manual facility are on/off switches for individual thruster supplies.

(5) An override switch panel. This allows certain microprocessor 'halt' conditions, for example 'discharge current below normal', to be manually overridden at the discretion of thruster operators, see Fig A1.

(6) Miscellaneous power supply 'level set' controls, interface logic, and buffer amplifiers etc.

(7) The power conditioner unit. This comprises the complete set of PWM thruster power modules. It is a prototype of the eventual flight PCU and was designed for high efficiency and reliability.

(8) An additional test feature not shown in Fig 4 is a 'dummy load thruster'. This can be connected to the output of the power conditioner, and provides a means of checking 'microprocessor plus PCU' performance in a basic way by representing all loads as resistive. This simple facility considerably reduced the amount thruster running during the 'debugging' phase of the work. Since the thruster, plus its attendant vacuum and cryogenic plant is expensive and time consuming to operate, the 'dummy load thruster' proved to be very cost effective.

(9) A complete set of rugged laboratory power supplies with associated monitoring facilities. Each supply is connected to the thruster via a two-pole two-way manually operated switch of 10 kV isolation. The equivalent PCU power supply is connected to the other two poles of this switch. If, for some reason, a PCU supply is not used, a laboratory power supply can replace it, indeed, changeover can take place whilst a sequence is in progress. This facility has proved to be very useful.

(10) A power conditioner junction cabinet with detachable perspex sides containing a distribution junction post which enables the connection of the dummy load thruster, or individual dummy loads, to the PCU. There is ample space inside the cabinet for the inclusion of monitoring equipment such as recording volt/ammeters, and 'clip on' dc ammeters, these latter, which detect the magnetic field around a current carrying wire, enable dc currents to be measured without physical disturbance of a power line.

The above described comprehensive set-up permits safe investigations to be expedited with a minimum of added wires, this is desirable not only for reasons of operational efficiency, but also because it enables stringent safety precautions, necessary due to the presence of potentially lethal high voltages, to be observed.

Various safety interlocks are incorporated. These need to be quite complex since, as already stated, parts of the PCU can be run together with parts of the laboratory power supply system. During the initial phases of the integration tests, when maximum accessibility was required, the +56 volts supply to the beam modules was replaced by +5 volts; giving instead of +900 volts, about +80 volts output. Fig 4 shows the microprocessor and (bread-board) PCU console.

4 PROGRAM DETAILS

The microprocessor program was written in Intel 8080 assembly language. This was assembled and edited by MSDS staff using, first, a GEC 4080 computer and later, the services of a time sharing computer bureau. The latter was more convenient and had a more powerful editing facility. The source program was then available in hexadecimal ASC II form on paper tape. This was converted to the binary (object) program using another computer conversion. The binary version could then be read into the microprocessor using the direct-memory-access (DMA) facility and an Addmaster 606 paper tape reader.

The program was developed and tested using the microprocessor, by reading from the current paper tape version via the DMA facility, into RAM, which was extended temporarily to serve as a volatile memory. The input/output (I/O) ports were connected to the microprocessor test-box so that commands could be input, and output signals could be displayed. The test and control unit allowed the program to be single-stepped and also manually edited, but had no provision to produce a hard copy, so this had to be done on the computer.

Once the program was satisfactorily checked in RAM using the LED test-box, a paper tape was produced and the ePROMS were programmed.

The program length was less than 1024 bytes, but greater than 768, so that four, 256×8 ePROM were required, though the fourth is only partly filled.

4.1 Microprocessor - PCU - thruster; integration

An activity carried out roughly in parallel with program writing was the incorporation of minor modifications into the PCU. These were to allow it to accept certain specific forms of microprocessor instruction such as the

incremental hollow cathode heater power program, the vaporiser high, low and closed loop conditions, also the discharge anode current and magnetic field current high and low states. Additionally, the maximum power output of the hollow cathode heater modules was increased. All modules were checked to prove that they functioned according to specification.

Integration was then carried out. An initial check of the sequence was made by connecting the microprocessor to the test unit. This was followed by connecting it to the PCU, which was in turn connected to the dummy load thruster (see section 3.2). Operation was substantially correct although some discrepancies were identified. For example, some indicator lamps were on when they should have been off and vice versa. More seriously, anomalies in the program were noticed, but it was considered that these could be better identified and dealt with during the next stage of integration.

In this phase the dummy load thruster was replaced by the T5 thruster. Time was then spent adjusting various module power levels, for example the high and low vaporiser currents. The initial power conditions, and overall power curves of the hollow cathode heaters, Fig 3, were also adjusted. Further information became available during these runs regarding the cause of the program anomalies. The most serious of these was that, during later stages of the sequence, the discharge current was switching back to 'low' when it should have remained at 'normal' and the vaporisers were switching back to 'low' when they should have been under closed loop control. The trouble was traced to logical discrepancies in the DELAY loop, the final version of which is indicated by the flowchart of Fig A2. These were corrected by modifying the DELAY loop (see Appendix), and reprogramming one ePROM. Other discrepancies were fairly trivial.

On the whole, the microprocessor-PCU-thruster integration exercise progressed much more smoothly than had been anticipated. For example, no problems arose due to thruster transients introducing spurious signals and the thruster remained remarkably stable and quiet whether operated on laboratory supplies or by the PCU. In addition, the complete freedom from inter-grid arcs observed during the life-tests of the T4A thruster was also found to be a characteristic of T5. It was also fortuitous that the aforementioned logical discrepancies in the DELAY loop could be rectified by quite minor modifications to the program.

Other factors contributing to the smoothness of the integration exercise were, the combination of laboratory power supply availability, a flexible monitoring system (which did not prejudice safety), together with readily

accessible bias adjustment facilities, the latter enabling problem identification and subsequent solution to be speedily achieved. Also, the good accessibility of PCU circuit components, enabled minor modifications, such as changes in resistor values, to be accomplished without difficulty. Finally, the personnel involved were familiar with most of the system, the only new features being the micro-processor and its peripherals.

5 EXTENSION OF THE ROLE OF THE MICROPROCESSOR

The work described above represented the first experience that any of those involved in the integration work had had with microprocessors. Thus, only during later stages was enough insight into the potentialities of these devices gained to enable consideration of the much fuller role that they could play in the design and operation of ion thruster power conditioners. A preliminary consideration of reasonable possibilities suggests that the total PCU component count could be reduced very considerably. Although much detailed evaluation and experimental work needs to be done, present rough estimates suggest that if certain non-microprocessor derived simplifications are included as well, the PCU component count could be reduced by as much as 50%, with all the consequent impact on mass, volume and reliability that this implies.

A study of PCU sequencing will show that some power supplies are on when others are off. Consequently, a single dc-dc converter power supply module, having a given power output capability, can accomplish tasks previously requiring two or more modules if suitable programming and switching arrangements are made. To realise this objective, alternative outputs must be provided together with, in some cases, extra transformer output windings. Power would be switched, as necessary, by program instructions. Additionally, suitable instructions would permit switching to be done off-load. Further, in some other cases the feeding of two loads simultaneously from the same source should present no serious problems.

An example of the first type could be a combined neutraliser cathode heater and neutraliser keeper power source. In this case heater power is not required once the keeper arc has struck.

An example of the second type could be the discharge magnet supply which at present, delivers about 4 watts. This could be an 'auxiliary' of the discharge keeper supply which at present provides, typically 4-5 watts but could deliver considerably more. The magnetic field current could be separately stabilised by simple circuiting which would take account of both voltage and resistance variations.

An almost complete elimination of the three-vaporiser power supply is possible. This would be done by writing into the program a set of subroutines that define vaporiser 'power on', and 'power off' mark to space ratios, such as to provide the high and normal vaporiser power levels described earlier. Implementation of this method of generating average power levels is aided by vaporiser time constants of about 1 minute, thus pulse repetition frequencies can be quite low. In fact a low frequency PWM system has in the past been successfully used to control vaporisers in closed loop experiments¹⁰. The labour involved in writing the additional program should be easily justified by the dramatic reduction in component count that would result. The present three-vaporiser module which has reasonably complex power control circuits, would be replaced by simple semiconductor switches. On the debit side, some additional memory space would be required, although this would incur no space qualification penalty since memory is required anyway, also an A/D converter would be needed to process closed loop error signals. These penalties are considered to be minor.

In addition to the microprocessor inspired simplifications discussed above, further beneficial PCU simplifications are now possible. These arise because the ion thruster performance is now well characterised and is unlikely to alter significantly in the future. As a consequence of this, options are now available that previously were not, this applies in particular to some data handling subcircuits.

6 CONCLUSIONS

The changeover from a hard-wired logic start-up and surveillance sequencer for the UK T5 10cm diameter ion thruster, to one using an Intel 8080A microprocessor has significantly advanced progress toward a flight operational system. The main advantage of this approach is that the new sequencer offers much greater flexibility with regard to sequence modification and updating. Further, the incorporation of a microprocessor opens the way to radical, simplifying, changes of power conditioner design by introducing the concept of multi-purpose power supplies to form a PCU of fewer modules. The greatly reduced component count should result in a smaller, lighter and more reliable PCU.

Appendix

SEQUENCE AND SURVEILLANCE FLOWCHART AND DELAY LOOP

MV = Main vaporiser (heater)	NB = Neutraliser bias
DV = Discharge vaporiser (heater)	NK = Neutraliser keeper
NV = Neutralizer vaporiser (heater)	PH = Pre-heaters
DK = Discharge keeper	BP = Back plate (heater)
DA = Discharge anode	AG = Accelerator grid (volts)
DM = Discharge magnet (field current)	BM = Beam (volts)
DC = Discharge cathode (heater)	NC = Neutraliser cathode (heater)

Referring to Figs A1 and A2, each power supply has an allocated box in the supply block. Its state can be read at any point in the sequence. A change of state is indicated by a bar below the supply state.

The various states are:

O = Off N = Normal C = Closed (analogue) loop
L = Low H = High Numerals indicate cathode heater power increment

In the case of DC and NC, the heater power level increment number is also given. L* or N* indicate that the supply is energised but its load is substantially open circuit awaiting the initiation of one of the two discharges. The time at which an arc will strike is, of course, indeterminate.

Fig A1 shows the program flowchart, only major blocks are shown. Some minor blocks, which would indicate a cathode heater power increment only, are omitted to prevent the flowchart becoming too long. Their presence is implied by the discontinuity of the NC and DC numerals, and by the bracketed numbers which indicate the number of DELAY loops entered (if more than one). These DELAY loops, described below, are shown in the small blocks, the numeral indicating the number of seconds delay.

For an experimental program it is desirable to have a manual override (o'ride) capability. The request for a decision whether to override is indicated by the lighting of an LED. A supervisor may then operate a toggle switch which allows the sequence to proceed despite a condition not having been met.

The DELAY loop or subroutine is shown in Fig A2. This performs several functions. Firstly it provides the required pauses between the various block activities. This it does by causing the program to traverse an inner loop 52 times, a number initially entered in the microprocessor's C register being

decremented during each traversal, 52 traversals taking 10 ms. When the C register is zero the program traverses an outer loop which resets the inner loop's C register, and decrements an outer loop number stored in the D, E register pair. When the D, E register is zero the DELAY loop is exited and further instruction or test activities are carried out. Whilst the inner loop is being traversed, checks are made on the status of neutraliser and discharge currents, thus, when an arc strikes, appropriate actions are taken. The minor delays, denoted DLY 1, DLY 2 etc are made up of non-operative instructions and are incorporated to make the inner loop traversal time independent of the route taken.

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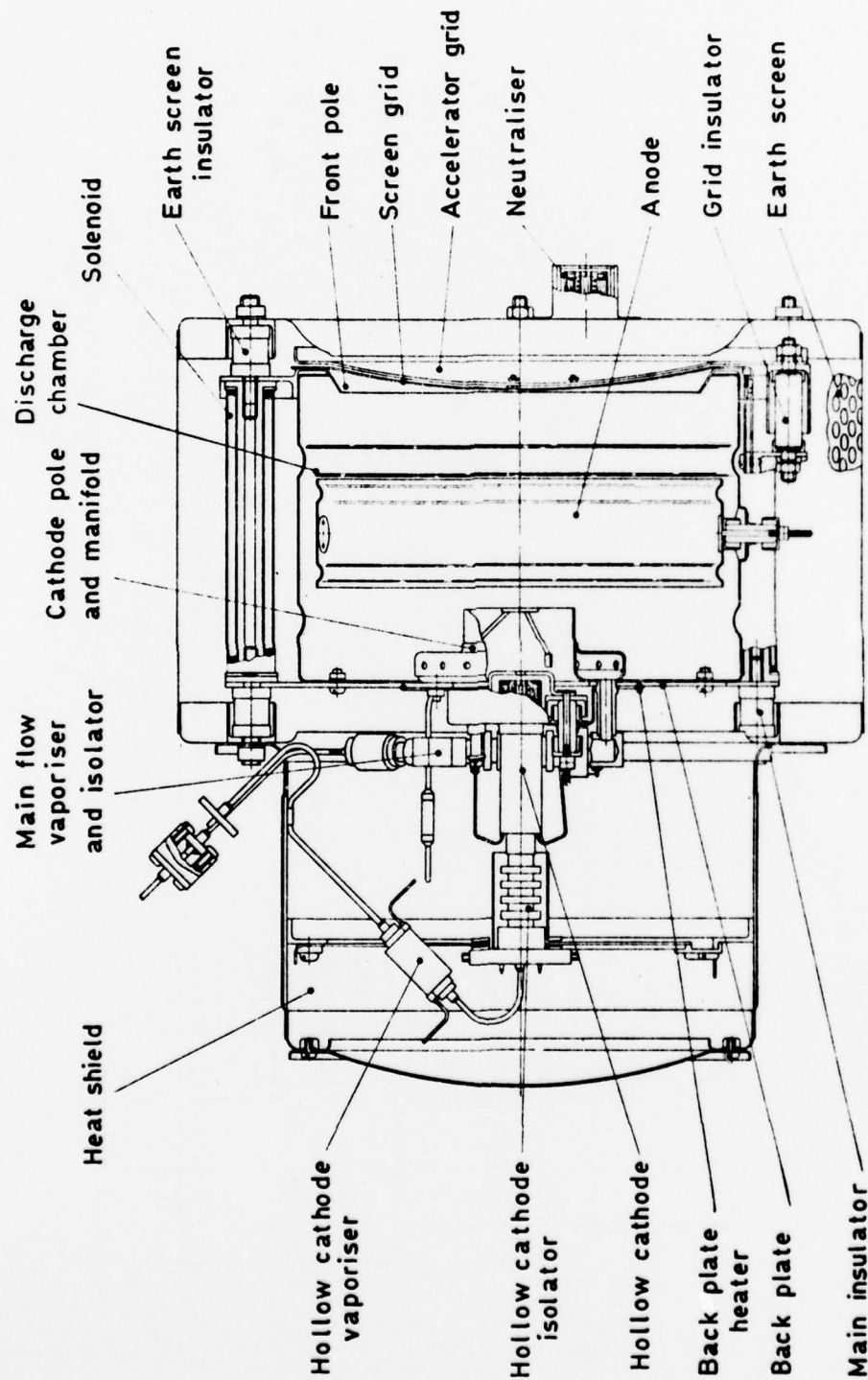


Fig 1 T5 thruster

Fig 2

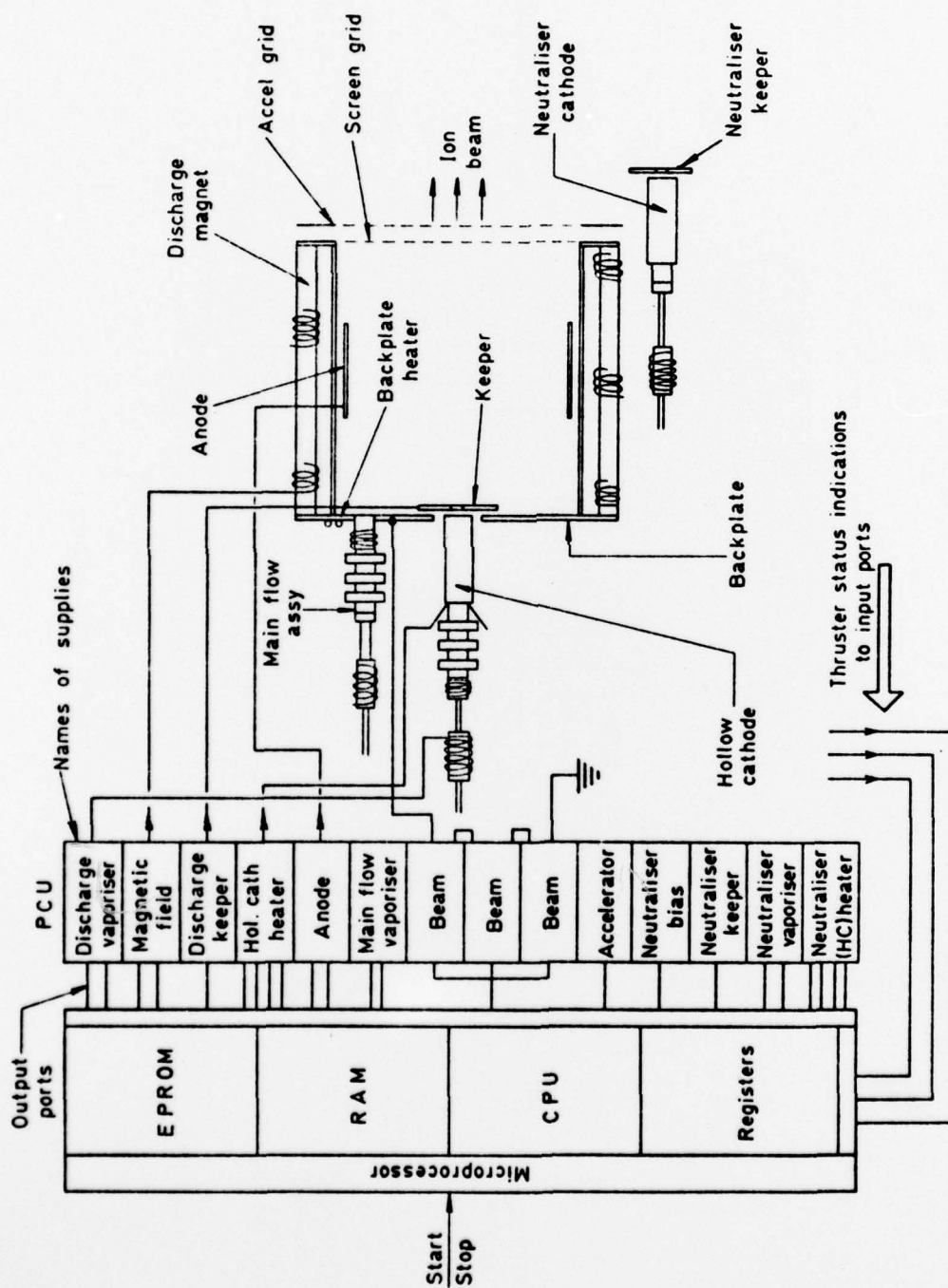


Fig 2 Schematic of microprocessor — PCU — thruster

Fig 3

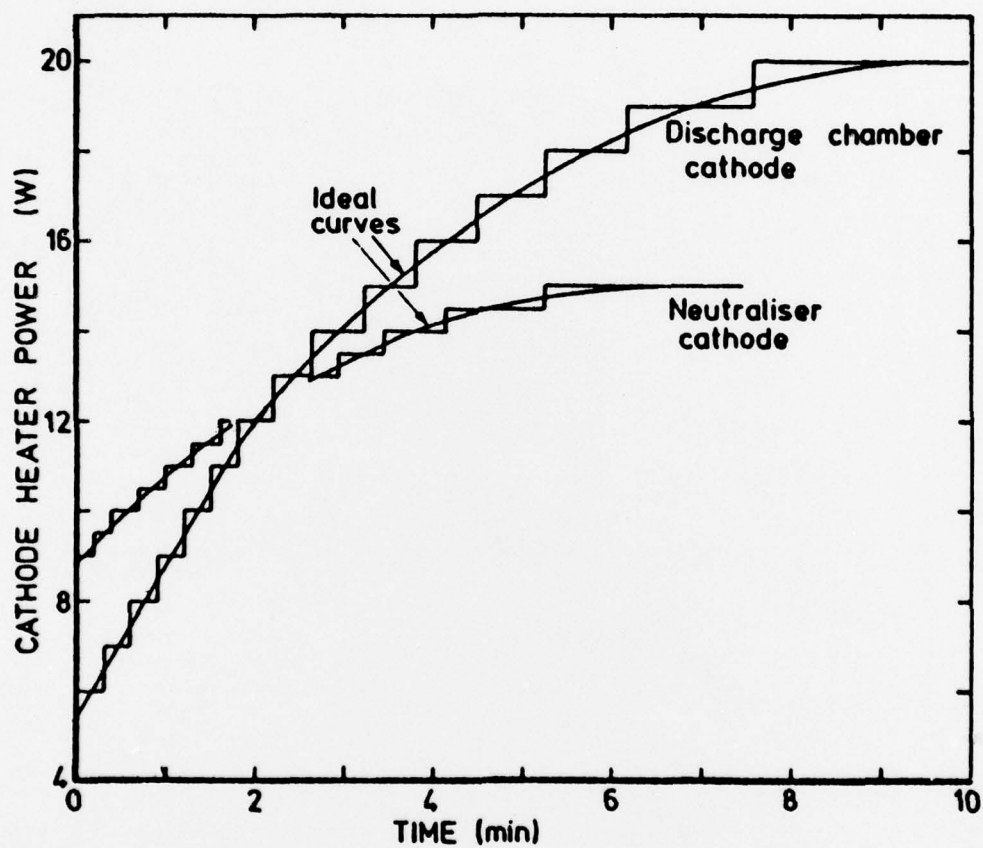


Fig 3 Time variation of cathode heater power

Fig 4

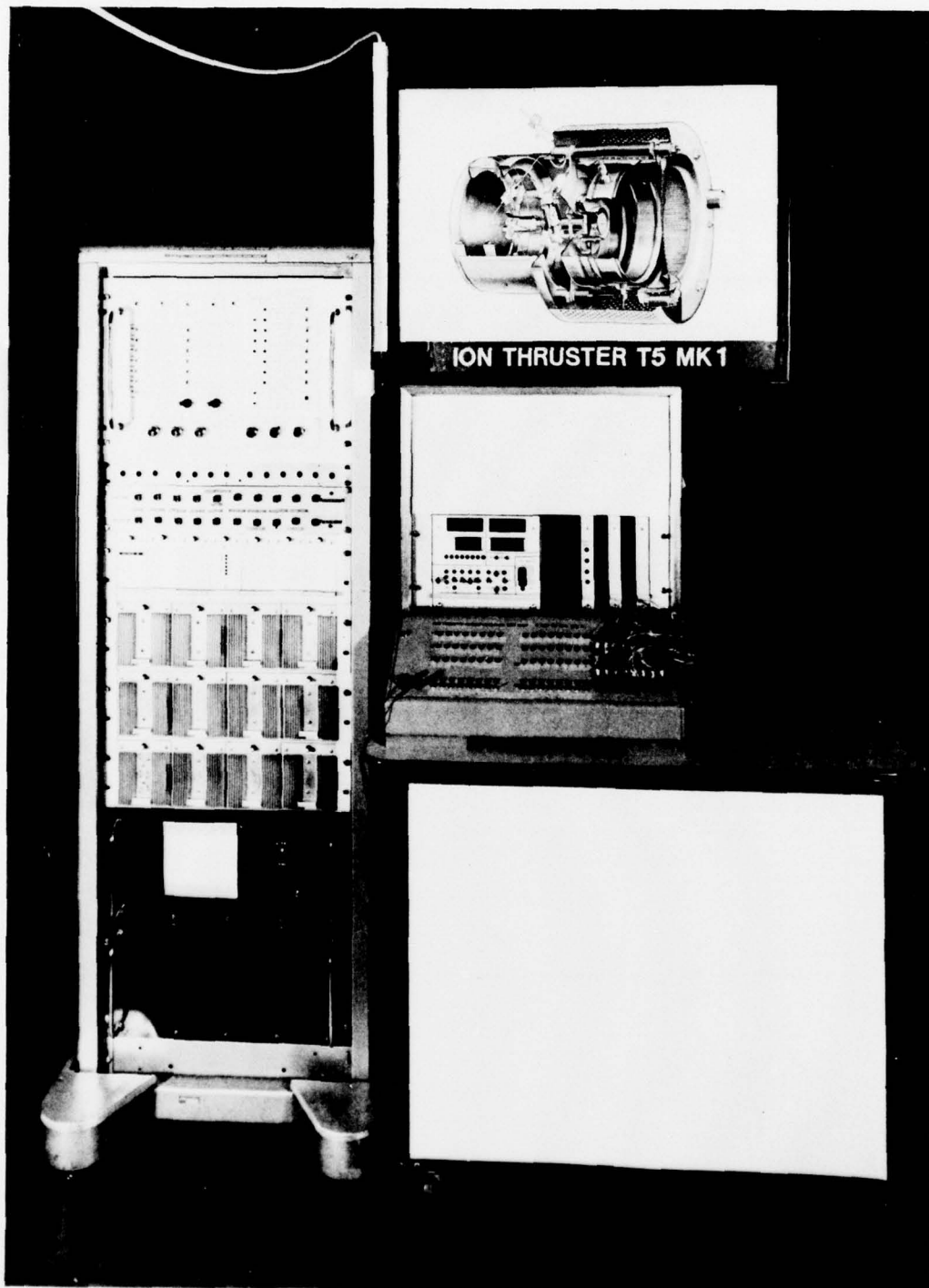


Fig 4 Microprocessor and PCU console

Fig A1

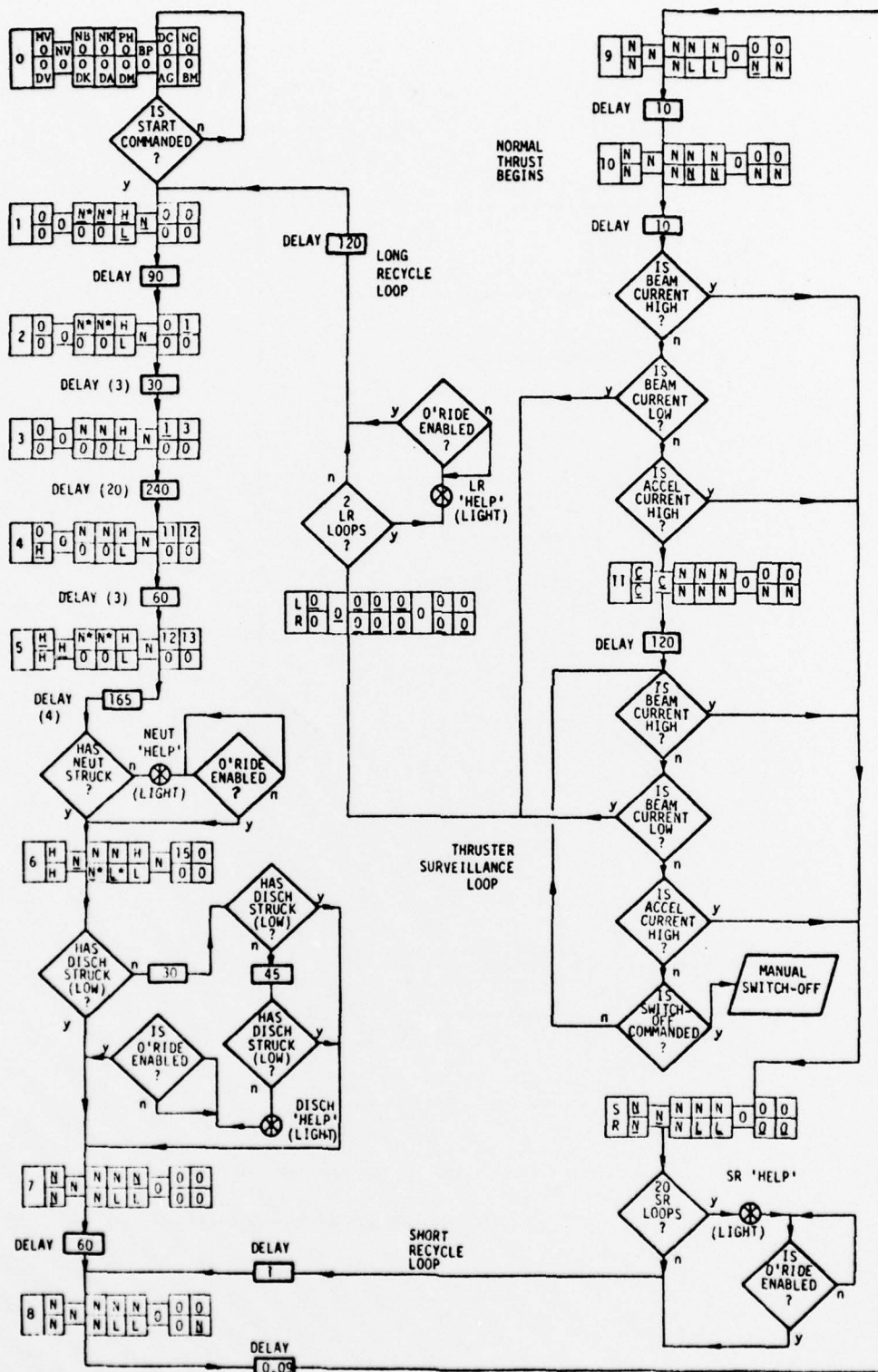
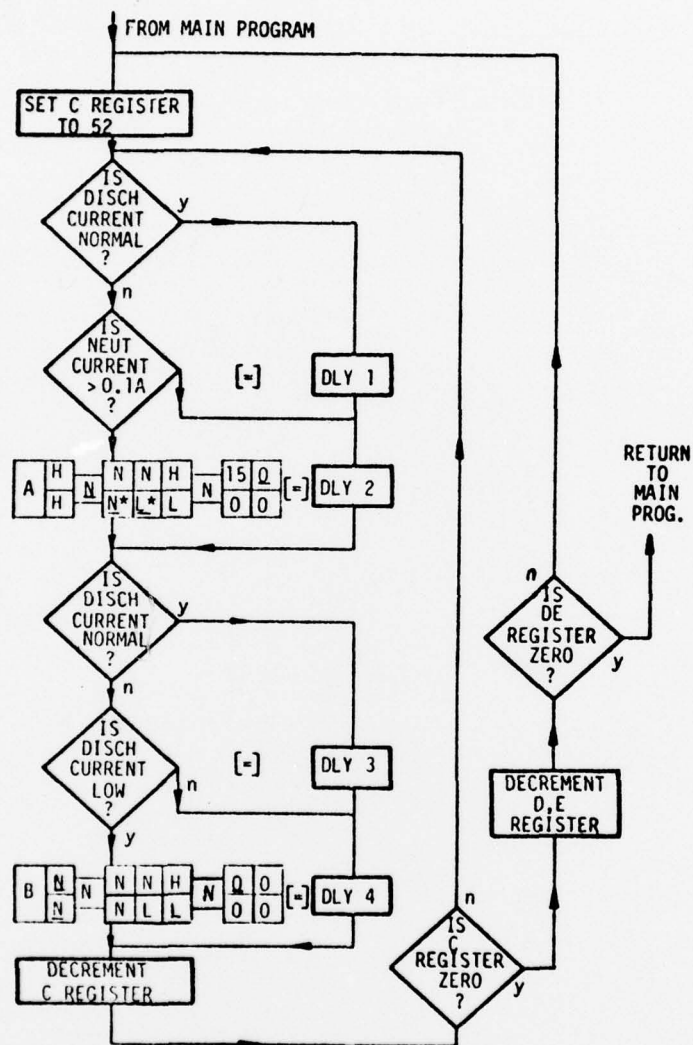


Fig A1 Sequence flow chart

Fig A2



NOTES:

- 1 [=]; execution time of DLY is the same as the function it bypasses.
- 2 Normal, low, refer to required normal or low setting.

Fig A2 Flow chart of delay loop

REPORT DOCUMENTATION PAGE

Overall security classification of this page

UNCLASSIFIED

As far as possible this page should contain only unclassified information. If it is necessary to enter classified information, the box above must be marked to indicate the classification, e.g. Restricted, Confidential or Secret.

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17. Abstract The Report describes a programme of work in which a previously existing hard-wired logic sequencer for the UK T5 10cm diameter ion thruster was replaced by a sequence generated by an Intel 8080A microprocessor. Details of the new system are given, together with background information relating to sequence requirements that arise from the thruster's electrical power needs. Electrical features of the ion thruster are described where relevant to the switch-on procedure. A second, minor, part of the Report proposes a logical extension to the use of microprocessors in the ion thruster power conditioner context. Such use would realize much more fully the potential of these devices, and would result in a reduction of the mass and volume of the power conditioner and increase its reliability.			

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