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AERONAUTICAL RESEARCH LABORATORY

MELBOURNE, VICTORIA

Technical Note 24

A MICROPROCESSOR CONTROLLER FOR A TOWING TANK DRIVE AND FLOW VISUALISATION SYSTEM

by

C.W. SUTTON
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Approved for public release.

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SUMMARY

D ED 1

This paper describes a microprocessor controlled system which enables test models to be towed at a predetermined constant velocity through water in a towing tank and provides camera trigger control for recording flow visualisation.

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1 INTRODUCTION

A towing tank has been constructed in which a scale model is towed through a water filled tank to allow visualisation of the flow pattern generated by the model. For an accurate presentation of the flow pattern the towing velocity must be controlled to produce the desired Reynolds Number for the prevailing environmental conditions.

The required run conditions are entered through a keyboard and are used by a microprocessor to set and control the desired linear velocity of a travelling carriage, with the model attached. Other features of the system include interactive calculation of parameters, programmable trigger positions for photographic records and the availability of raw or processed data to a plotter or printer.

2 SYSTEM DESCRIPTION

2.1 General

The towing tank (Fig. 1) is a five metre long water filled transparent channel with a 300 mm by 300 mm usable cross section supported on a six metre long steel frame. The underside of the carriage is fitted with linear bearings which freely glide along two accurately aligned parallel rails attached to the steel frame. A variable speed motor coupled to a speed reduction gearbox of 29:2 drives the carriage, with model attached, along the rails with a system of pulleys and belts.

A changeable drive pulley gives the user a choice of either 50 or 125 mm diameter that provides two overlapping ranges of stable carriage velocity resulting in a total usable range of 0.03 to 0.7 metres/second. A hand-held control unit allows the user to drive the carriage in either direction and to position the carriage for the commencement of a run.

2.2 Carriage Details

The carriage consists of an aluminium base plate with an adjustable aluminium frame that supports the model, lights and photographic equipment. Three linear bearings, beneath the carriage base, allow the carriage to travel smoothly along the two aligned rails for a distance of about 4.5 metres. The carriage is towed along the rails by a 4 mm diameter Kevlar cable that loops around a pulley at each end of the tank.

A rotary pulse transducer, attached to the rear edge of the carriage, is driven by a wheel that rolls along one of the guide rails. The generated pulses provide feedback to the constant velocity controller (Fig. 2) in the form of real-time data for calculation of the instantaneous position and velocity of the carriage (Section 3.3).

2.3 Water Towing Tank

The channel shaped water towing tank is constructed from five sections each 0.3 x 0.3 x 1.2 metres of clear perspex channel clamped together with watertight seals. Half a cubic metre of filtered water is required to fill the tank. A small amount of sodium sulphate is added to the water to improve conductivity and facilitate production of hydrogen bubbles by electrolysis (Ref. 1) for flow visualisation around the model.

2.4 Camera Trip Setting

The microprocessor resident program allows up to six flow visualisation photographs to be taken during each traverse of the model along the tank. The user specifies the points where the photographs are required, as percentages of the usable towing distance. During a run, as the model passes the software set trip positions, the camera shutter is automatically triggered to record an image and to advance the film.

As the user enters each camera trip position through the keyboard, the program calculates and displays the tim interval between the records, using the previously entered carriage velocity. This enables the user to check that there is sufficient time for the camera to advance the film and reset the shutter between consecutive trip positions.

The 35mm Single Lens Reflex camera attaches to the carriage. Alternatively, a video camera is used if the entire run needs to be recorded. All electrical cables for the carriage equipment freely extend to minimise changes in cable drag on the carriage.

2.5 Velocity Measurement

During a run the average carriage velocity is measured within a distance window that can be specified by the user. By default, this window is one metre long and commences 1.5 metres from the start position of the carriage. Motor speed is controlled by an interrupt service routine that is called every 4.7 milliseconds. The number of times (count) the routine is called, while the carriage is within the window width (ww), enables the model velocity (mvel) to be calculated using equation 2.1. Corrections are then made to the motor speed.

$$\text{mvel} = \frac{100 \times \text{ww}}{4.7 \times \text{count}} \tag{2.1}$$

To provide reasonable accuracy in the measurement of the average velocity the:

- minimum window width (ww) available to the user is 0.8 metres
- window is not locatable within a metre of the start position

2.6 Parameter Calculation

Five parameters are available for defining the model's environment:

1. Water Temperature
2. Kinematic Viscosity
3. Model Length
4. Reynolds Number
5. Carriage Velocity

The ambient water temperature is entered by the operator prior to commencement of each run otherwise the temperature (temp) defaults to 15 degrees Celsius.

The kinematic viscosity (vis) is calculated from equation 2.2.

$$vis = (1.679 \times 10^{-6}) \times (e^{-0.025} \times temp) \qquad (2.2)$$

The model length or chord (len) is then entered (default setting is 0.15 metres).

If the user enters a specific carriage velocity (vel) for the run, the corresponding Reynolds Numbers (Rey) is calculated using equation 2.3. Alternatively, if the desired Reynolds Number is entered then the corresponding carriage velocity is calculated using a transposed equation 2.3. The default settings of Reynolds Number and carriage velocity are 50000 and 0.18 metres / second respectively.

$$rey = \frac{(vel \times len)}{vis} \qquad (2.3)$$

3 CONTROL INSTRUMENTATION

3.1 General Description

The towing tank controller consists of the following five types of VME bus cards in a standard single height Euro Card module (Fig. 3a) that is wired for external access through the back panel connectors (Fig. 3b).

- Central Processor Unit (CPU)
- Random Access Memory and Read Only Memory (RAM & ROM)
- Asynchronous Communications Interface Adaptor (ACIA)
- Real Time Clock (RTC)
- Remote Operations via Peripheral Interface Adaptor (PIA)

The CPU card contains a Motorola MC68000 clocked at 8 Mhz. The assembler code is address mapped (Fig. 4) into ROM and RAM from 0000 to IFFFF (Hex).

The RTC card provides the date and time for labelling of runs. Two trickle charged Nicad batteries provide back-up power when the mains supply is removed.

One of the two serial ACIA cards controls communication to the plotter and printer and the other ACIA card controls the transfer of data to and from the auxiliary port and terminal. The auxiliary port was used during development of the controller to down-line load programs into the RAM card from a laboratory microprocessor development system. The port communicates with a host computer at 2400 baud. Memory locations assigned to each port, are shown in Fig. 4. The serial communication boards uses the Synertek SY6551 ACIA integrated circuit.

The PIA card is configured (Appendix A contains details) to:

- respond to all pulses generated by the pulse transducer
- provide pulse width control for the motor
- generate carriage velocity data
- monitor the states of all safety limit switches

- monitor the states of the hand-held control switches
- generate pulses to trigger the camera

Details of the allocation of pins for the A & B digital input / output ports of the PIA are in Table 1. Port A checks the various switch states and port B checks the system status. The camera is triggered by 0.5 second wide 5 volt pulses, initiated by narrow width pulses from the microprocessor that triggers a pulse stretcher 556 timer.

3.2 Motor Switching

The usable speed range of the DAVEY 32 volt 17 ampere DC drive motor is from 420 to 1200 Revolutions Per Minute (RPM) and is controlled by pulse width modulation. Below 420 RPM the motor torque is insufficient to produce satisfactory drive and at speeds above 1200 RPM the control sensitivity rapidly deteriorates. The control range of the pulse width duty cycle (pulse width as a percentage of the repetitive period) corresponding to the above speed range is between 20% and 60% of the 4.7 millisecond pulse repetition period.

Power is switched to the motor during the time that the pulse width modulation signal is at a logic low state to avoid undesirable motor operation should the pulse switching line become open and float to a logic high state. The pulse width modulation is controlled by the count values loaded by the microprocessor into a timer. The timer is clocked at 0.8 Mhz. and decrements to zero from the loaded value, by one count every clock pulse. A loaded value of 3760, clocked every 1.25 microseconds, equates to a timer delay of 4.7 milliseconds and a 100% duty cycle. The program limits the loaded value to 3200 to ensure that the maximum motor speed is typically below 1200 RPM.

The schematic diagrams (Figs. 5 and 6) shows the motor supply, solid state switch, interface details and the hand-held control unit. All inputs to the motor power supply are electrically isolated via optical couplers. Data bit PB7 (Pin 17) provides the variable pulse width to switch the motor current through four parallel power transistors connected in a Darlington configuration.

Data bit PB5 (Pin 15), operates an ON/OFF relay that switches power to the motor. When PB5 is logical high the power is 'OFF'. Data bit PB4 (Pin 14) operates a two pole relay that controls the motor direction by reversing the polarity of the 28 volt motor supply to the motor armature. A time delay in the program prevents the ON/OFF relay from operating until the reversing relay has changed over.

3.3 Pulse Transducer

The instantaneous carriage position and velocity are periodically derived from the carriage mounted ONO SOKKI type RP-432Z optical rotary pulse transducer which generates 1024 pulses / revolution. The pulse transducer is rotated by a friction drive wheel 65.19 mm diameter that is in continuous contact with one of the stationary rails to generate 5 pulses / mm of linear travel of the carriage. The transducer output pulses pass through a Schmitt trigger and differential line driver (externally mounted on the transducer housing) then through a long shielded twisted pair cable to the PIA card.

The instantaneous carriage position is referenced to the start position by a counter that accumulates the total count of transducer pulse received. The carriage velocity is derived from another counter which is read and reset by an interrupt service routine, called by the leading edge of every transducer pulse. This counter is clocked every 1.25 microseconds (0.8 Mhz) so the accumulated count relates to the time taken for the carriage to travel 0.2 mm. An acceleration value is available by progressively taking the difference between consecutive velocity values.

As the carriage speed increases a lower count is achieved and so degrades the accuracy of the velocity evaluation. To improve the accuracy of the velocity calculation the transducer pulse rate is frequency divided by five to increase the accumulated count value and so provide a velocity calculation for every one millimetre of carriage travel.

An inherent time delay occurs before the interrupt service routine reads the counter. From Appendix B the delay approximates 8 counts (12 microseconds) and this is compensated for in the velocity calculation algorithm (equation 4.1).

3.4 Hand-Held Control Unit

The remote hand-held control unit provides forward, reverse and stop facilities for manual positioning of the carriage. The bit designations to the PIA that service the unit are shown in Table 1.

The hand-held control unit is keyboard selected from the menu. When the STOP button is held down for more than one second program control transfers from the hand-held control unit to the keyboard.

3.5 Limit/Emergency Switching

The distance between the permanently installed start and finish trip switches is currently 4.55 metres. Whenever the carriage reaches the software limit of 95% of travel (or the finish switch is tripped representing 100% of travel) the carriage is decelerated in a controlled manner by linearly decreasing the pulse width modulation to stop the motor. A summary of the run characteristics is then displayed on the screen.

Two override switches at opposite ends of the tank define the extreme range of travel and are electrically connected in series with user actuated emergency manual stop switches installed at conveniently accessible locations near the tank. These switches are not software sensed but when tripped directly deactivate the ON/OFF power relay to remove the supply voltage from the motor. Once tripped these switches must be manually reset to restore motor power.

4 CONTROL PROGRAM

4.1 Mechanical Considerations

Before the control program could satisfactory control the carriage velocity the original mechanical drive system needed improvements.

The carriage drive arrangement exhibited a dominant natural frequency of about six Hertz. Several mechanical imperfections excited the natural frequency to produce noticeable variations in carriage velocity that the controller could not eliminate. These velocity variations were reproduced in the records generated by the microprocessor controller during open-loop and closed-loop runs.

A servo accelerometer, clamped to the carriage, provided an acceleration profile of the carriage motion, to independently confirm the velocity variations and contribute to identifying the source of the problems.

The original sash cord hauling system was replaced by a Kevlar cable driven by a vee belt through a changeable pulley and a 29:2 speed reduction FESCA QUALOS type 1.125W gear box attached to the motor shaft. Although the low speed driving torque improved and the velocity variations were reduced, the accelerometer signal detected a damped oscillation at the start of a run followed by small periodic disturbances, at a frequency corresponding to the rotational rate of the drive pulley. However, the upper range of usable carriage velocity was increased to 0.7 metres / second.

4.2 Controller Description

Early control algorithms were generally ineffective in providing a constant carriage velocity because of velocity variations introduced by mechanical defects, in particularly those that related to eccentric pulleys, non-uniform belts and semi-elastic towing cord.

Significant improvement occurred with acceleration feedback that was applied immediately the desired carriage velocity was reached after starting the run. Zero acceleration control dominated and the carriage travelled at near constant velocity. Unfortunately, any changes in mechanical load that decelerated the carriage during a run caused the carriage to quickly settle to a new but unspecified constant velocity.

Repeatability of absolute carriage velocity was enhanced by closed-loop operation compared with the original open-loop system that required the user to make periodic corrections to the motor drive mark to space ratio, to compensate for unidirectional drift in motor speed with changes in the temperature of the motor field winding.

The present controller algorithm accepts the desired carriage velocity, (or Reynolds Number) as keyboard entered by the user, and computes the reference count from equation 4.1 prior to starting the run.

$$\text{refcnt} = \frac{200}{(\text{vel} \times \text{piaclk})} - 8 \qquad (4.1)$$

The reference count represents the time for the carriage to travel one millimetre at the desired velocity and corresponds to the expected hardware counter value for zero velocity error.

Throughout the run the hardware counter value is compared with the reference count to generate error corrections for the controller which incrementally adjusts the pulse width modulation applied to the motor by changing the offset value. The initial offset value is only used at the start of a run.

Measurements confirmed that the velocity error was minimised when the controller feedback corrected the offset value once in every five interrupt calls, instead of on every call. The motor ON pulse is repetitively generated every 4.7 milliseconds but the controller adjusts the pulse width modulation at 23.5 millisecond intervals.

To reduce starting transients a ramp acceleration brings the carriage to within 90% of the desired velocity before controller feedback is activated.

A four point Chebyshev Interpolation curve was evaluated (Appendix C) for each of the two drive pulleys using open-loop data. An accurate curve was not required as motor speed was known to change with temperature in open-loop use. The resultant Chebyshev Coefficients (Table 3) are used to obtain the initial offset value.

Throughout each run the controller compares the actual carriage position against the entered camera trip settings that were automatically stored in ascending order prior to the start of the run. When a trip position is reached the controller generates a voltage pulse to trigger a pulse stretcher that activates the camera shutter. The actual positions where the camera shutter operated are stored as data by the controller.

When 95% of carriage travel has been completed the controller implements a software controlled braking routine to halt the carriage (Section 3.5).

5 SYSTEM PERFORMANCE

Towing performance was assessed against three criteria:

- Velocity operating range 0.03 to 1.0 m/s
- Absolute velocity error < 1.0%
- Velocity stability < 1.0%

The system performance was obtained using the controller velocity measuring facilities. Absolute velocity was measured with a commercial high frequency counter gated by carriage interruption of two light beams, separated a known distance apart. For the two available drive pulleys that fit to the output shaft of the gearbox the following measured velocity ranges were obtained:

DRIVE PULLEY DIAM. (mm)	**CARRIAGE VELOCITY RANGE** (Metres/second)
50	0.03 to 0.3
127	0.3 to 0.7

Two methods were used to measure the carriage velocity variation within the two ranges as being between 0.5% and 2%.

- The controller plotter option (recorded the velocity error count within a window)
- A servo accelerometer attached to the carriage (provided a full acceleration profile)

The signal generated by the carriage mounted servo accelerometer was recorded on an analogue X-Y plotter (Fig. 7). Once the starting transient settled the acceleration signal remained approximately zero to indicate that existing velocity fluctuation components were small.

The servo acceleration signal (Fig. 7) shows that carriage acceleration settled to near zero about two seconds after to the start of the run that was programmed for a velocity of 0.7 metres/second. The system provided near constant velocity during the next four seconds as the carriage travelled the remaining three metres of tank length.

6 OPERATING INSTRUCTIONS

6.1 Menu Description and Operation

Menu driven software is provided to simplify the towing tank operations. At switch on default values are initially assigned to all parameters but are overwritten by user input values. Table 2 shows the main menu that has nine options selectable by typing the appropriate lower case letter.

6.1.1 Parameters

Typing 'p' displays the parameter setting options. The system characteristics that may be changed are:

- RUN NUMBER - automatically increments once at the start of every run
- WATER TEMPERATURE - entered by the user
- KINEMATIC VISCOSITY - calculated from the water temperature
- MODEL LENGTH - the chord value entered by the user
- REYNOLDS NUMBER - entered (or calculated from the kinematic viscosity, model length and the specified velocity)
- CARRIAGE VELOCITY - entered (or calculated using Reynolds Number) and is applicable only for closed-loop operation
- OPEN LOOP - entered as the motor pulse value (offset) for the motor speed

If the user changes the Reynolds Number then a new carriage velocity is automatically calculated. Similarly, if the user changes the carriage velocity then a new Reynolds Number is calculated. Included with every recalculation is a display of:

- Pulley size (50 or 127 mm diameter) for optimum motor control for the run
- Estimated run time in seconds

Typing 'O' returns the user to the main menu.

6.1.2 Camera

Typing 'c' while in the main menu displays the camera setting options:

1. Film Number
2. Aperture
3. Shutter Speed
4. Model Incidence
5. Position of Light Plane
6. Cathode Current
7. Photograph Trip Position

All the camera setting details, except the photograph trip positions, are simply stored by the controller as data and have no influence on performance. A maximum of six photograph trip positions may be entered by the user.

A trip position is entered by typing '7' followed by the desired location, expressed as a percentage of travel from the start position. All valid values are sorted into ascending order then displayed, with the time interval between consecutive camera shutter operations calculated from the pending carriage velocity. A trip position is removed by typing '7' followed by the negative value of the unwanted position.

Typing 'O' key returns the user to the main menu.

6.1.3 Motor Operation

Typing 'm' while in the main menu accesses the four motor operation options:

1. Check Warnings
2. Commence Closed-loop Run
3. Commence Open-loop Run
4. Velocity Window Position

Typing '1' displays current warning messages that affect the systems operation, such as a limit switch that is tripped.

Typing '2' or '3' initiates carriage motion.

Closed-loop operation uses the programmed velocity value. Open-loop operation uses the Motor Pulse value (offset) displayed in the parameter menu.

At the completion of a closed-loop or open-loop run a summary of the specified run parameters, the measured average carriage velocity and the corresponding Reynolds Number is displayed on the terminal.

Typing '4' enables the measurement window start and finish positions to be altered.

An error message is displayed if the window width become less than 0.8 metre. The window determines from which portion of carriage travel the velocity error data are gathered, for optional output to the plotter or printer.

Typing 'O' returns the user to the motor operation options menu.

6.1.4 Data Presentation

Typing 'd' outputs data, gathered from within the window, to the printer. The velocity and controller characteristics may also be included in the print out by responding positively to the APPEND (Y/N)? question.

Typing 'g' produces a graph of the velocity error, as measured within the window, with the vertical axis scaled to represent ± 4% of the programmed velocity. When all data are dumped to either the plotter or the printer the program returns automatically to the main menu. Either device may be interrupted by typing 'I' which return the user to the main menu. Time and date are appended to hard copy outputs.

6.1.5 Hand-held Control Unit

Typing 'h' causes the program to enter the hand-held control unit mode that allows the user to control the carriage motion in both directions. Carriage movement results from holding down either the FORWARD or REVERSE switch. Motion ceases when FORWARD or REVERSE switch is released.

The STOP switch, when pressed and released, stops the carriage motion during open-loop or closed-loop operation. Pressing the STOP switch for longer than one second automatically returns the user to the main menu.

6.1.6 Time and Date

Typing 't' causes the program to enter a routine to modify the current calendar setting. The day is entered by typing in the first two letters of the day followed by a carriage return. Date and time entry requires groups of two digits with a space or comma as the delimiter. Date uses the DD MM YY format. Time uses the HH MM SS format. Carriage returns for date and time are automatic. On completion of the sequential entries, the program returns to the main menu.

6.1.7 Scale Plotter

Typing 's' allows the user to modify scaling and details of the output plot. However, a knowledge of plotter syntax (Ref. 2) is required as a string of 30 characters defining the new information, followed by a carriage return, needs to be entered.

Typing 'O' returns the user to the main menu.

6.1.8 Monitor Program

Typing 'o' causes the software to enter a machine code monitor program that allows the user to examine, test and alter memory locations or communicate with a host computer. This facility was added to allow further development of the main controller.

7 FUTURE IMPROVEMENTS

Because of recent significant performance improvements in personal computers (PC's) it should now be practical to implement the real-time control functions of the microprocessor controller with a high performance PC using conventional input / output interfacing to the towing tank hardware.

Future development could extend the capability of the system to transfer raw or processed data to a host computer. Installation of a temperature to digital converter would allow the water temperature to be read directly by the controller.

A mechanical improvement would include the installation of true running drive pulleys. Performance evaluation would be simplified by using a carriage mounted servo accelerometer connected to a digital storage oscilloscope with integration facilities.

8 CONCLUSION

The towing tank microprocessor controller incorporates many facilities and provides a significant improvement over the original open-loop system. Measured performance indicates that a usable carriage velocity was achieved throughout the range 0.03 to 0.7 metres / second with a maximum velocity variation of less than 2.0%. Results were repeatable and predicted vortex flows were observed around the aerodynamic shapes that were tested.

ACKNOWLEDGMENTS

The work was initiated by Dr D. Thompson. Installation of the instrumentation hardware and evaluation to confirm reliable pulse count operation with bi directional carriage motion was performed by I.M.Kerton.

REFERENCES

1. Sutton C. W. and Anderson R. J. A Pulsed Power Supply for Hydrogen Bubble Flow Visualisation. ARL Aero TM 315, April 1979.

2. SE2284 Economy Documentation Plotter - User's Manual, BBC Goerz Metrawatt.

3. EO 1 AEF - NAG FORTRAN Library Routine Document. Numerical Algorithms Group Ltd, Oxford, U.K., Mk8, 12 January 1981.

APPENDIX A

Program Configuration and PIA. Timer/Counter Functions

Two SY6522 dual programmable timers (packages U9 and U10 in Fig. 8) reside on the PIA card and provide the digital signal interface. Codes, preloaded into specific registers, enable the function of each timer to be independently set.

Timer T1 package U9 is configured as an astable multivibrator which changes state every 2350 microseconds. Positive transitions occur every 4700 microseconds and are used to produce level 1 interrupts to the 68000 microprocessor.

Timer T1 package U10 functions as a monostable multivibrator. A value determined by the constant velocity control algorithm is loaded into registers 4 and 5 to set the next "one shot" period, which is the pulse width for the motor speed control. This occurs every 4700 microseconds, when the service routine is called by the level 1 interrupt from T1-U9.

Timer T2 package U9 counts the number of negative edges generated by the carriage mounted rotary pulse transducer during a run. The accumulated count is a measure of the distance the carriage has travelled from the start position. The count value is repetitively accessed by the main program to implement controlled braking, store carriage data within a pre programmed window and generate trigger pulses to actuate the camera.

Timer T2 package U10 measures the interval between consecutive positive edges of the carriage mounted rotary transducer pulse train, to determine velocity. Each positive edge from the transducer initiates a level 2 interrupt to the 68000 microprocessor causing the service routine to read registers 8 and 9 of the timer before resetting them. The registers contain the number of "E" clock pulses that were counted since the previous level 2 interrupt. The "E" clock output from the 68000 microprocessor is the 8 Mhz CPU clock divided by 10, so that each count registered by T2-U10 has an interval of 1.25 microseconds.

The carriage mounted pulse transducer generates five pulses for every millimetre of carriage travel and so the instantaneous carriage velocity is available to the control algorithm. An acceleration value is also obtained, from the difference between the previous and the current counts.

In order to obtain a higher count value and reduce the significance of count scatter caused by time variations within the hardware and the execution of the level 2 interrupt service routine, a divide by five was incorporated in the CA1 line of T2-U10 to produce a count interval which corresponds to one millimetre of carriage motion.

Count scatter occurs in T2-U10 because the level 2 interrupt and the CPU clock are not synchronised but a major source of count scatter is caused by the completion of the current microprocessor instruction before the service routine is called. Thus, before the interrupt takes effect, a random variable delay can occur within the limits of the shortest and the longest execution time of instructions contained in the main program loop or lower priority level 1 service routine. Therefore long execution time instructions, such as "multiply" and "divide", were avoided in the real-time control algorithm. Similarly, "movem" and "long word" instructions were excluded from the main loop program and service routines.

All real time activities such as the implementation of the control algorithm, setting the motor pulse width, data acquisition, distance checks and the generation of camera trigger pulses are processed within the main program in the time slots between interrupt servicing. For effective operation the main program needs to loop in typically less than two milliseconds.

As the carriage velocity increases, the time between level 2 interrupt calls decreases and so reduces the time available for executing other real-time operations within the main loop. This required the level 2 interrupt service routine to be written for minimum executable time. A faster "entry to exit" time for the level 2 interrupt service routine was achieved using the relatively slower "memory to memory move" instructions, instead of faster "data register move" instructions which then involve additional instructions to save and restore the working data register.

The unlatched 16 bit counters (T2-U9 and T2-U10) are each read in two bytes in the following order:

1. Read the upper byte

2. Read the lower byte

3. Reread the upper byte

If the upper byte is unchanged then pack the upper and lower bytes as the counter value

If the upper byte has changed then reread the lower byte and pack the two latest read bytes as the counter value.

Such a precaution increases the program execution time slightly, but eliminates the occasional large error, caused by time slew between reading the upper and lower counter bytes when the upper byte increments by one and the lower byte returns to zero (an event that occurs every 256 counts).

APPENDIX B

Error Considerations with Interrupt Service Delays

1 MOTOR PULSE WIDTH

During carriage travel two service interrupt routines are called. The lower priority routine is called by a timer every 4.7 milliseconds to control the motor pulse width and the higher priority routine is called by the rising edge of the carriage mounted pulse transducer. Hence, whenever the lower priority routine is interrupted to allow the higher priority routine to be serviced, a delay of up to 180 clock pulses may occur before the motor pulse is initiated.

Such a delay causes a momentarily change in motor speed which in practice is negated by the motor inertia. The maximum delay of 180 CPU clock cycles represents 22.5 microseconds and is also relatively small compared with the minimum remaining 'OFF' time of 1880 microseconds in the cycle when the motor is running with a 60% duty cycle (Section 3.2).

2 CARRIAGE VELOCITY

The CA1 interrupt is activated by the rising edge of the carriage mounted pulse transducer. However, a delay of up to 20 microseconds may exist before this interrupt is serviced and reads counter T2-U10. A mean error correction of approximately 12 microseconds (8 counts at 0.8 Mhz) was incorporated into the software to minimise this source of carriage velocity error.

APPENDIX C

Chebyshev Interpolations

To improve the response time of the system, separate curves were constructed to evaluate the approximate width of the motor pulse for the specified velocity with the 50mm and 127mm diameter pulleys. As the pulse width varies with motor temperature the curves were not exact and an interpolation function, based on four points, was constructed by a series of Chebyshev Functions.

Chebyshev Function $T = \cos(n \cos^{-1} x)$

where: $$x = \frac{(2x - xmax - xmin)}{(xmax - xmin)}$$

Interpolation Function $q = 0.5\, a_0 T_0 + ... + a_{n-1} T_{n-1}$

Trigonometric functions were avoided in the evaluation as the Chebyshev Functions were approximated to polynomials.

$T = 1$
$T = x$
$T = 2x^2 - 1$
$T = 4x^3 - 3x$

Using data from Table 3 and a computer library routine (Ref. 3) the Chebyshev coefficients for both pulley diameters were evaluated for use by the controller program.

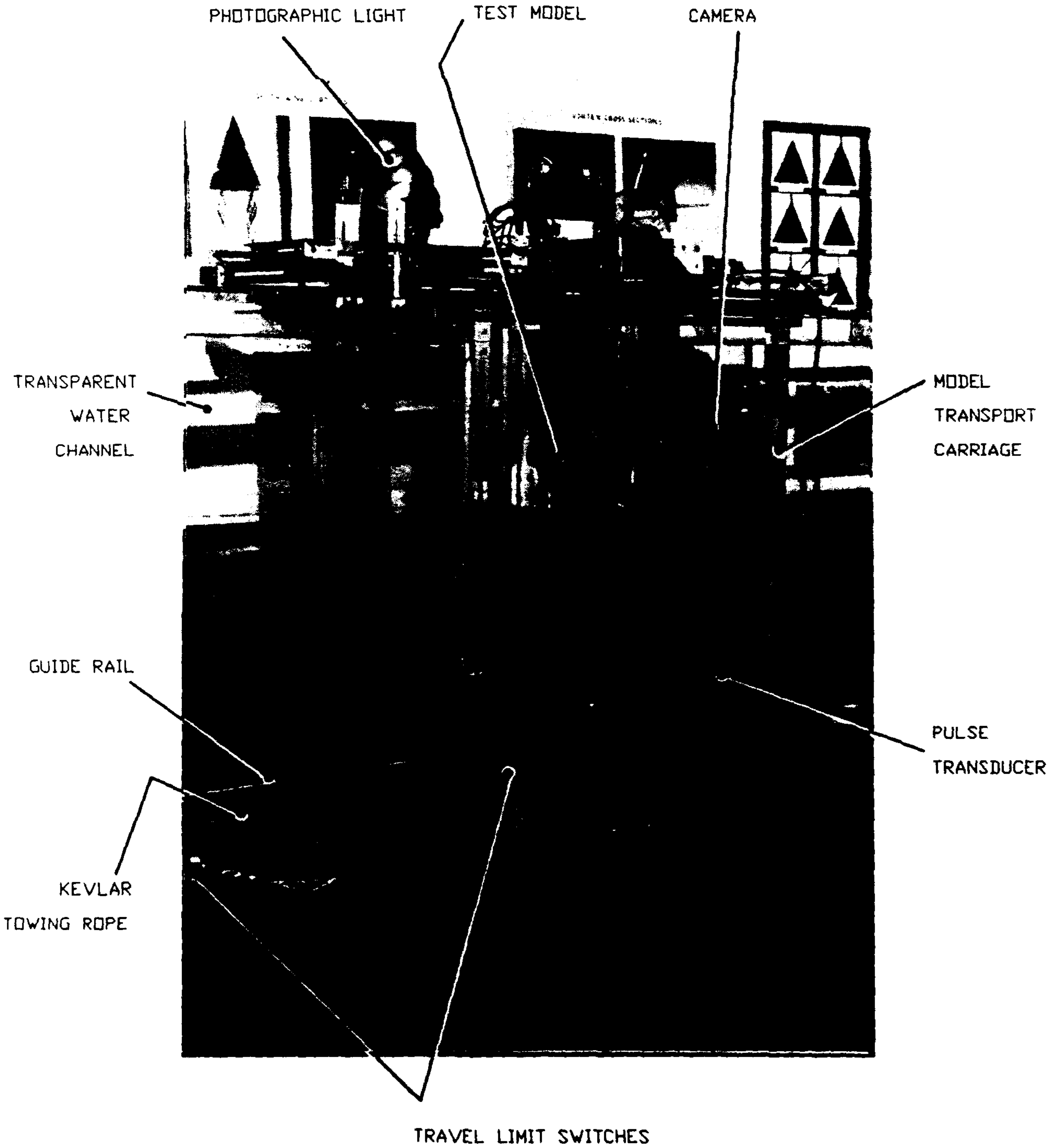


FIG 1 TOWING TANK MODEL CARRIAGE

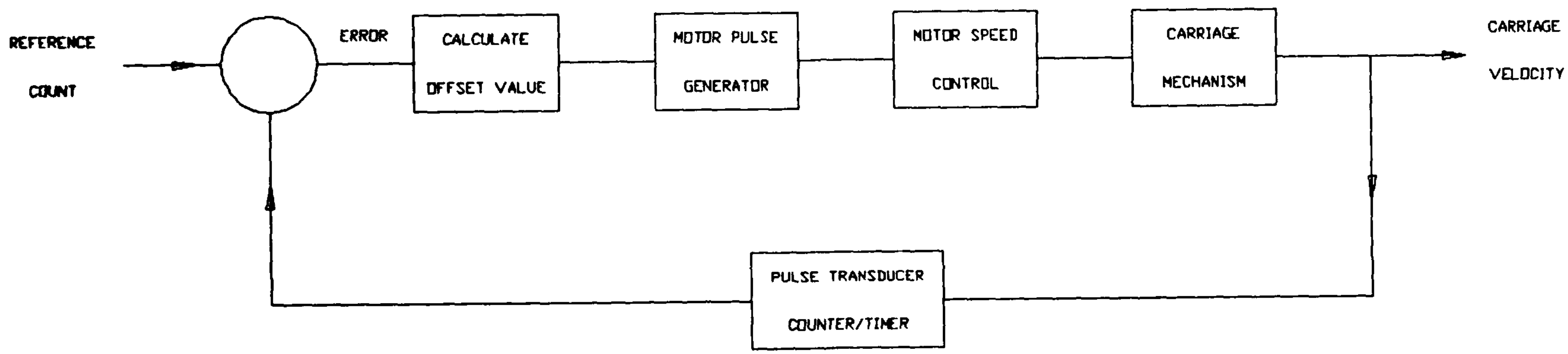


FIG.2 CONTROLLER FEEDBACK LOOP

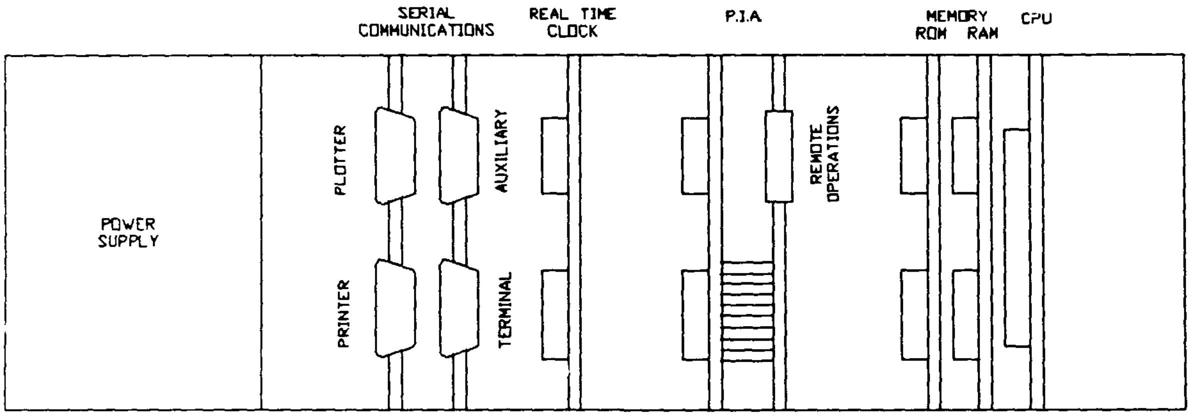


FIG.3a BOARD LOCATIONS (REAR VIEW)

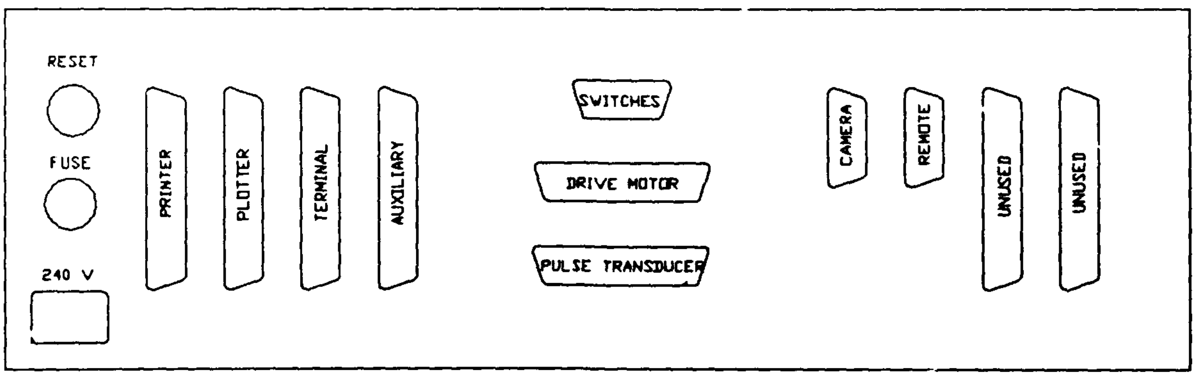
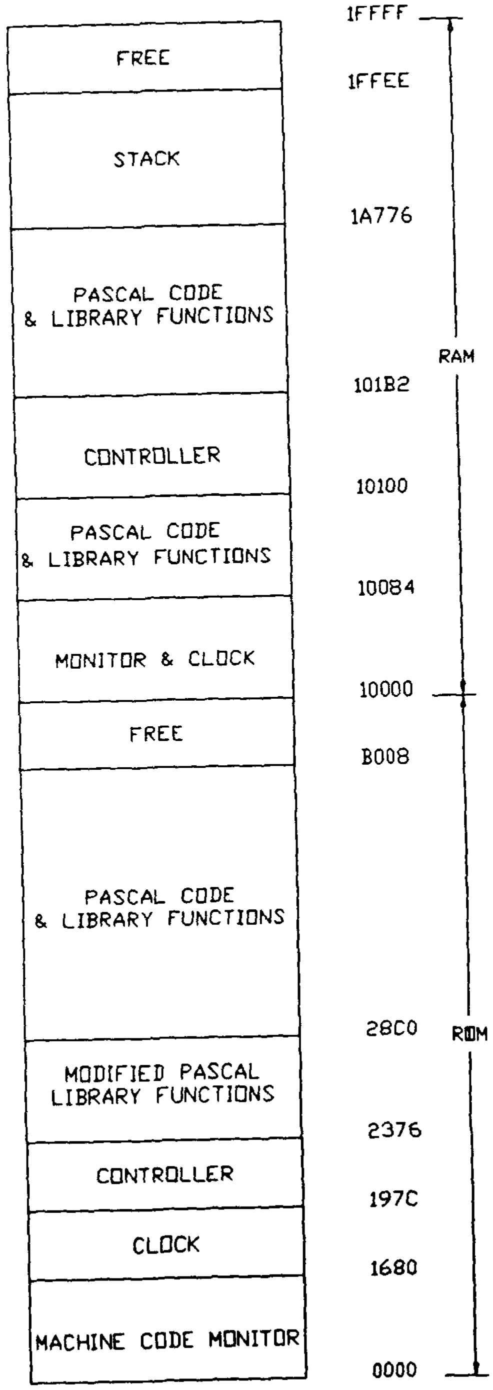


FIG.3b REAR PANEL CONNECTIONS



CARD	PORT ADDRESS
ACIA	
PLOTTER	FFFF69
PRINTER	FFFF68
AUXILIARY	FFFF61
TERMINAL	FFFF60
PIA	FFFE20
RTC	FFB001

FIG.4 MEMORY MAP

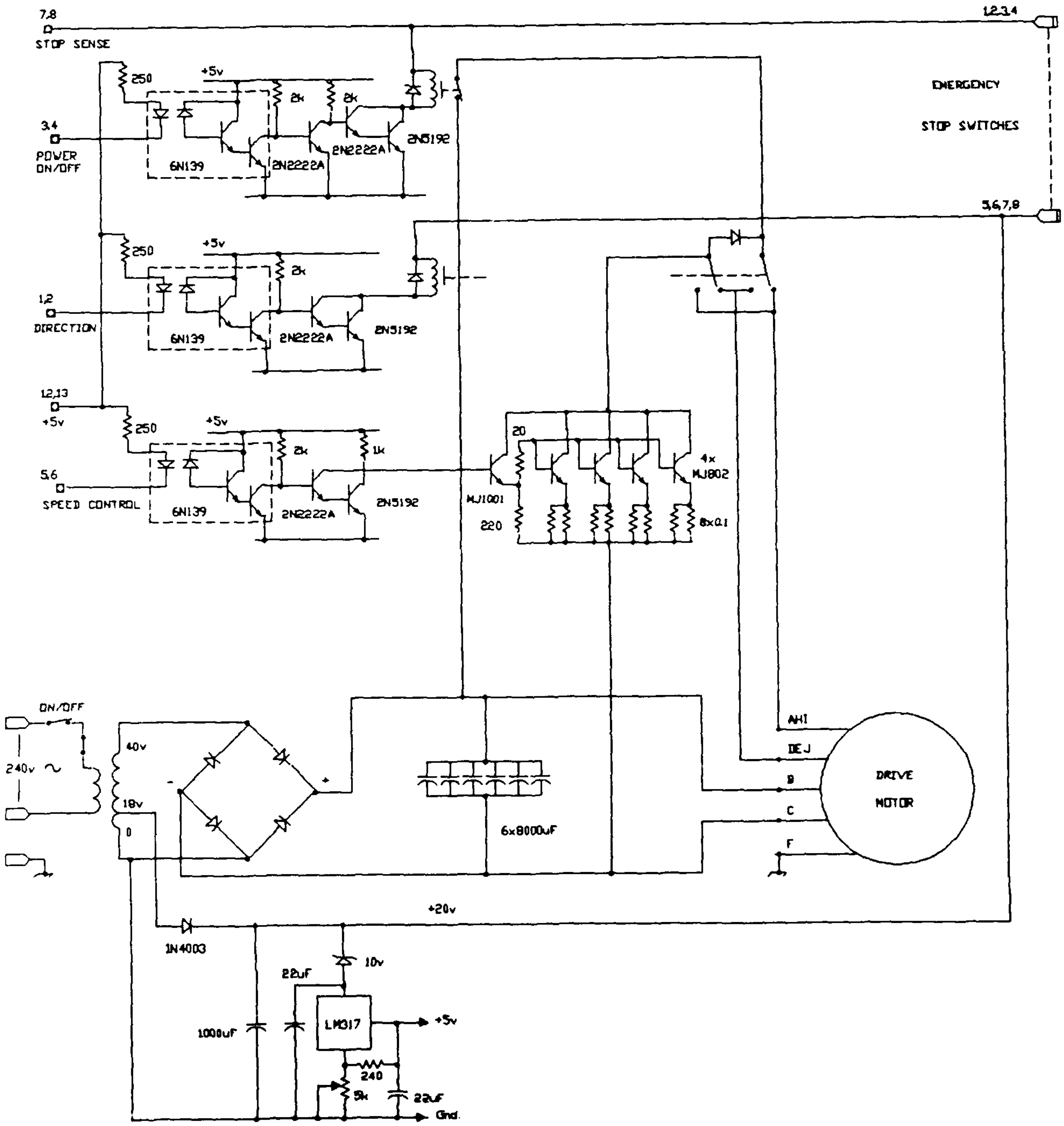


FIG.5 MOTOR POWER SUPPLY

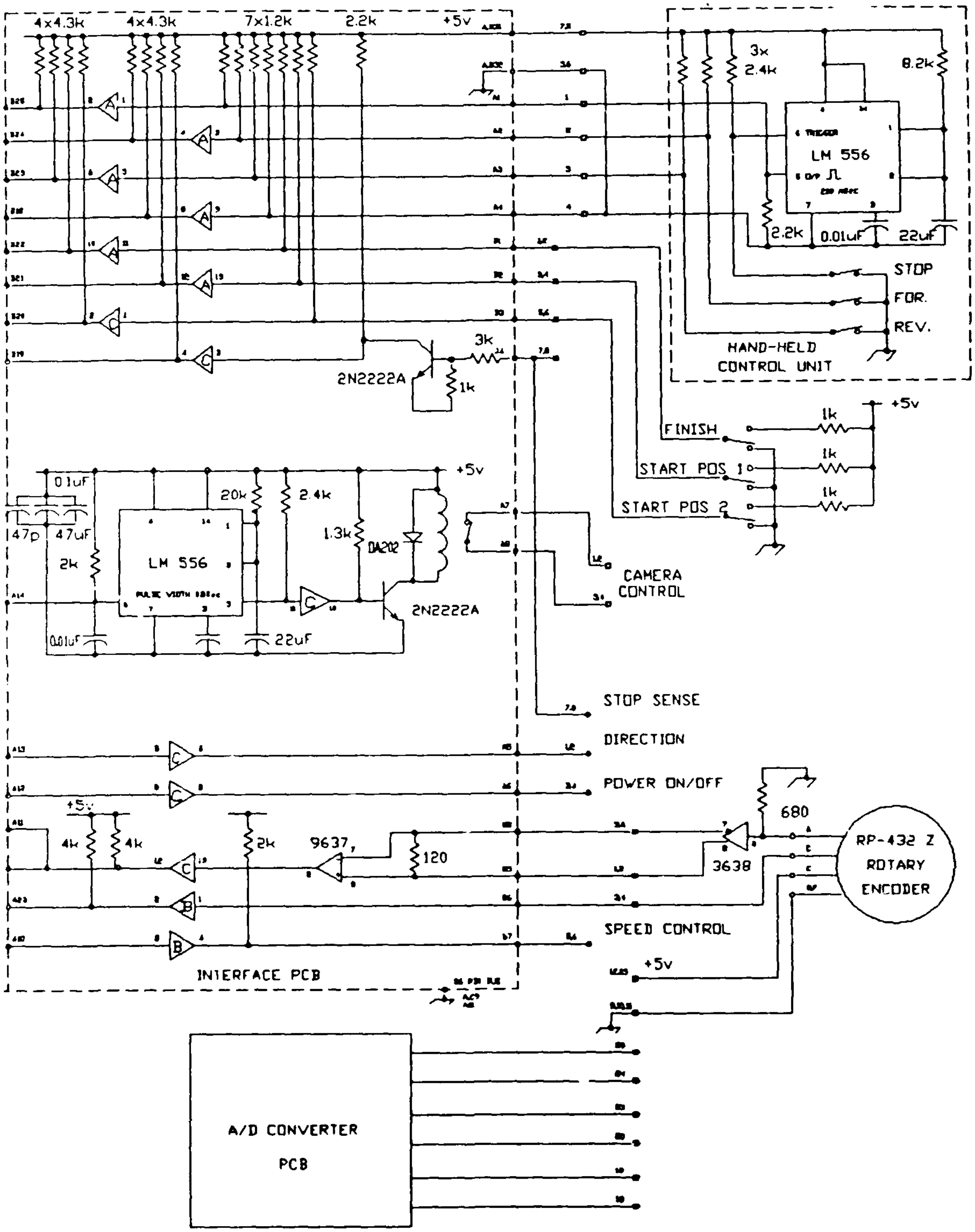


FIG.6 TOWING TANK CONTROL UNIT

Typing O returns the user to the main menu.

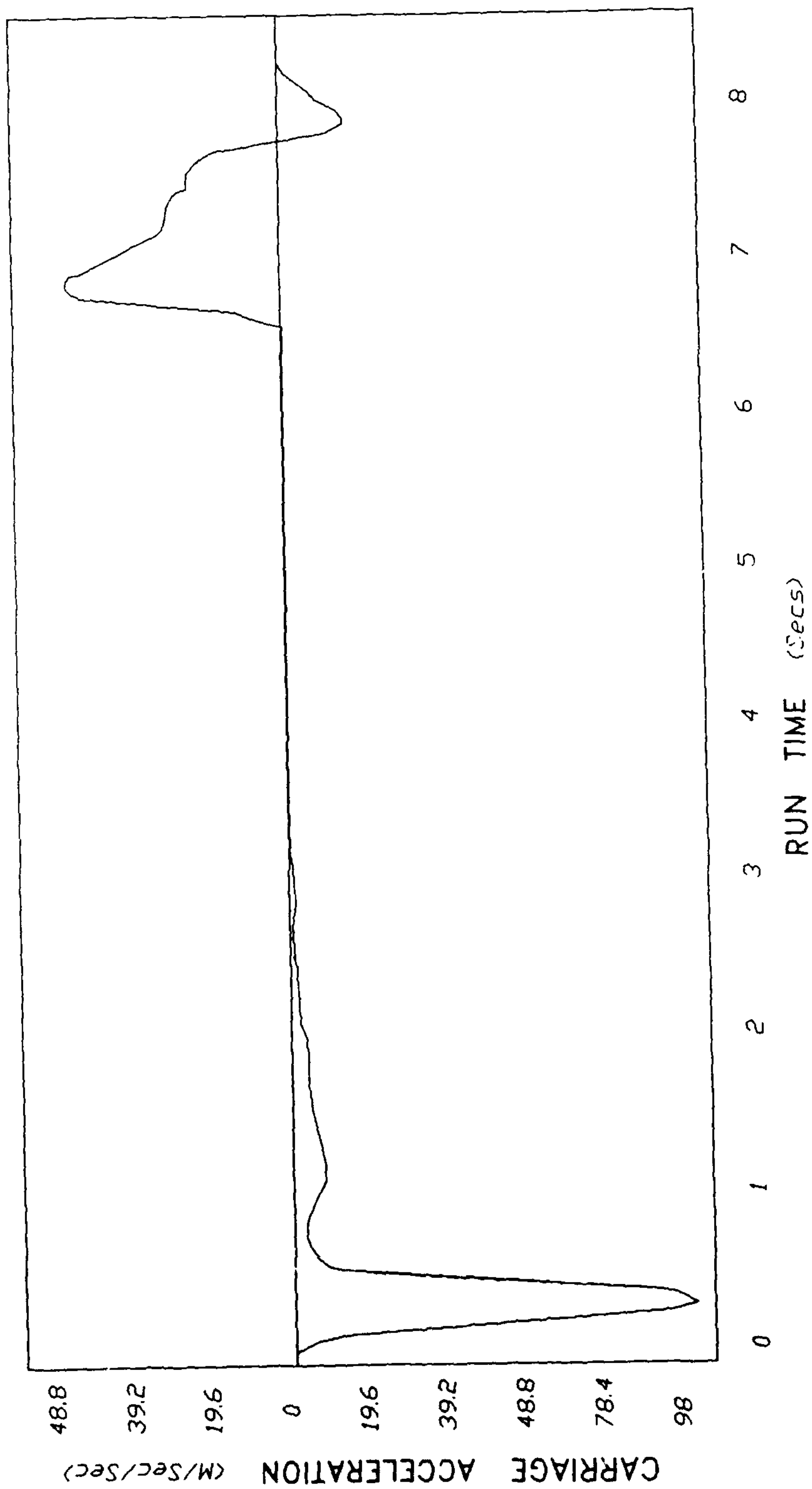


FIG 7 ACCELERATION RESPONSE AT 0.7 M/SEC.

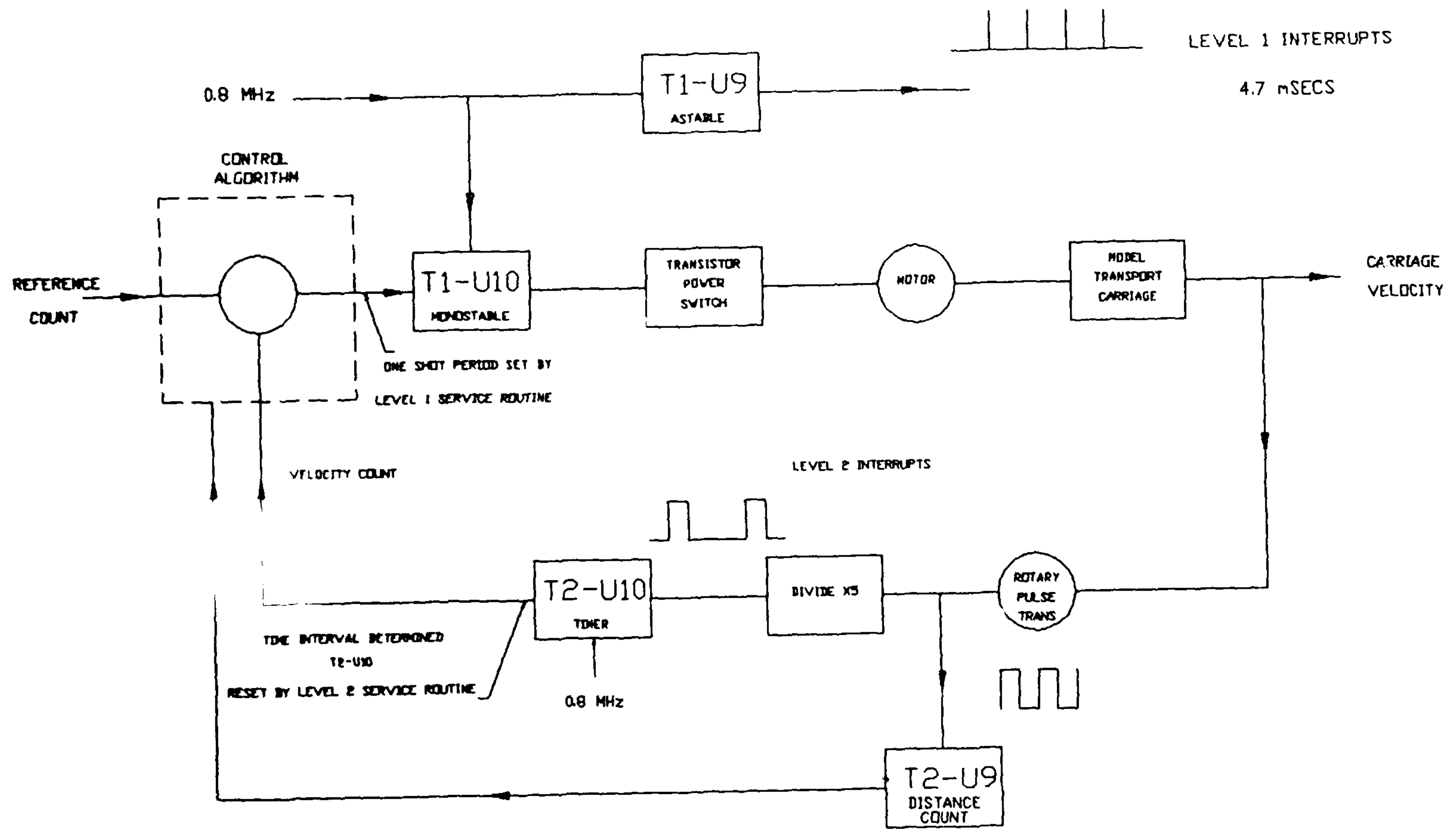


FIG.8 PIA COUNTER/TIMER FUNCTIONS

BIT	Port A FUNCTION	LOGIC STATE
PA0	Hand Held Unit	High to Stop
PA1	Hand Held Unit	Low for Forward
PA2	Hand Held Unit	Low for Reverse
PA3	Finish Run Limit Switch	High when Tripped
PA4	Start 2 Limit Switch	High when Tripped
PA5	Start1 Limit Switch	High when Tripped
PA7	Safety Limit Switch	High when Tripped
PA7	Safety Limit Switch	High when Tripped

BIT	Port B FUNCTION	LOGIC STATE
PB0	Not Used	
PB1	Not Used	
PB2	Not Used	
PB3	Camera Trigger	High to Trigger
PB4	Motor Direction	Low for Forward
PB5	Motor On/Off	High for power off
PB6	Pulse Transducer	Typically square wave
PB7	Motor Speed	Variable pulse width

TABLE 1 PIA PORT INTERFACE CONNECTIONS

	MAIN MENU		OPTIONS
(p)	Parameter	(1)	Run Number
		(2)	Water Temperature
		(3)	Kinematic Velocity
		(4)	Model Length
		(5)	Reynolds Number
		(6)	Carriage Velocity
		(7)	Open-Loop Motor Pulse
		(0)	Exit
(c)	Camera	(1)	Film Number
		(2)	Aperture
		(3)	Shutter Speed
		(4)	Model Incidence
		(5)	Position of Light Plane
		(6)	Cathode Current
		(7)	Photograph Positions
		(0)	Exit
(m)	Motor Operation	(1)	Check Warnings
		(2)	Commence Closed-loop Run
		(3)	Commence Open-loop Run
		(4)	Velocity Window Position
		(0)	Exit
(h)	Hand-held Control Unit		
(d)	Data to Printer	(y)	Append Characteristics
		(n)	Exclude Characteristics
(g)	Graph Velocity Error on Plotter		
(s)	Scale Plotter		
(t)	Time and Date	(su,mo,tu,we,th,fr,sa) Day (DD MM YY) Date (HH MM SS) Time	
(o)	Monitor Program	Type 'H' for help menu	

TABLE 2 MENU DETAILS

PULLEY DIAMETER (mm)	PULSE COUNT (units)	SPEED (metres/second)
50	100	0.030
	1000	0.149
	2500	0.279
	3000	0.295
127	900	0.302
	1600	0.300
	2300	0.600
	3000	0.659

OPEN-LOOP DATA FOR INTERPOLATIONS

COEFFICIENT	PULLEY DIAMETER (mm) 50	127
a_0	2730-530	3871-158
a_1	1220-191	1277-777
a_2	323-400	335-579
a_3	268-483	166-678

CHEBYSHEV COEFFICIENTS FOR INTERPOLATION

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