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TRACK GEOMETRY MEASUREMENT SYSTEM SOFTWARE MANUAL

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FINAL REPORT

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16. Abstract

This report documents the Track Geometry Measurement programs that have been implemented on the UNIVAC 1616 computer. The programs include prerun parameters and achieve information entry and real-time data processing programs.

Sections on track geometry techniques and on the sensor system are provided as background for the program.

Appendices have been provided on the data processing algorithms and on the UNIVAC 1616 hardware.

17. Key Words
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PREFACE

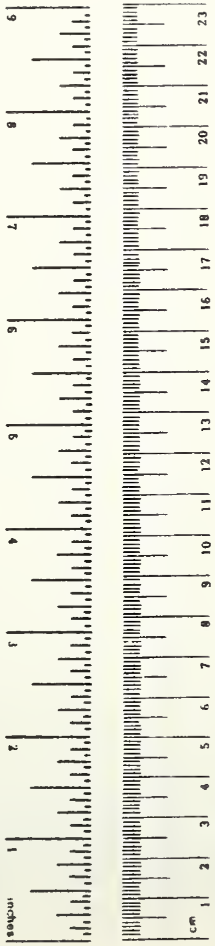
The Urban Mass Transportation Administration, Technology Development and Deployment, Office of Rail Technology is sponsoring programs directed toward improving urban rail transportation systems. The Transportation Systems Center is supporting UMTA by providing systems management and technical support for the Urban Rail Supporting Technology Program (URSTP) in the design, construction, and operation of UMTA test facilities; the analysis and testing of vehicles, components, and guideways; and the development of key technological data and systems. The track geometry measurement system (TGMS) described herein was developed under the URSTP to provide rail properties with the capability of automatically measuring four track geometry parameters in real time with equipment that can be installed on their own vehicle.

The software for the TGMS was developed by the following people (listed alphabetically): Ellen Benoit, George Blum, David Brownell, and George Eddleston. The integration and smoothing algorithmn was developed by Peter Mengert. John Cadigan, Paul Poirier, and Richard Robichaud were responsible for the data acquisition, processing, and display equipment. Lowell Babb, John Nickles, Gunars Spons, and Robert Wilmarth were responsible for the TGMS sensor equipment and the UPS equipment. TGMS analysis was the responsibility of John Nickles. The TGMS development effort was under the management of George Neat.

METRIC CONVERSION FACTORS

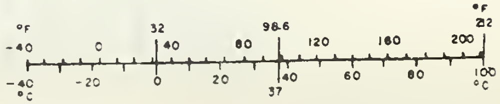
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.18	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

The Track Geometry Measurement System (TGMS) was developed through the United States Department of Transportation's, Urban Mass Transportation Administration by the Transportation Systems Center in Cambridge, Massachusetts under its Test and Evaluation studies to aid transportation planners and maintenance personnel to better assess the quality of track for rapid rail, light rail, and commuter rail systems.

The purpose of this document is to describe the TGMS real-time software and provide operating instructions for its use. The TGMS real-time software collects and stores raw data from the TGMS sensors, processes the raw data to compute track geometry parameters, and records and displays the processed data. All of these functions are performed in real time as the raw data is being collected. The current version of the TGMS real-time software is designated TGM6C.

The remainder of Section 1 is a background of the TGMS sensor system and a description of the three major TGMS subsystems followed by an overview of the interrelationships of the three subsystems. Sections 2 through 4 discuss the system software programs used in the TGMS. Section 5, the Operating Instructions for implementing the software programs, includes system validation, HEADER operation, TGM6C operation, and the brush recorder calibration procedure.

Appendixes A through I are the details of engineering applications and software listings peculiar to the TGMS.

Appendix H is a Glossary of Terms.

1.1 BACKGROUND

The TGMS was developed to aid transportation planners and maintenance personnel to better assess the quality of track for rapid rail, light rail, and commuter rail systems. It is adaptable to any resident vehicle on any rail transit system. Since the sensor equipment is designed to be installed on any vehicle, the "footprint" recorded is representative of the vehicle that actually travels the track being inspected. The sensors can be adapted to any vehicle by using appropriate mounting bracketry.

The TGMS dynamically measures those geometric parameters of track which affect ride quality, noise, and operational safety. All parameters are processed in real time on-board the vehicle using a UNIVAC 1616 digital computer. The system is designed to operate at revenue speeds ranging from 20 to 80 mph.

The specific parameters measured by the TGMS include rail gage, alignment, profile and cross level. These parameters are defined here and discussed in more detail in Subsection 1.1.2.

Parameter	Definition
Gage	The distance between the rails measured 5/8 inch from the top of the rail head.
Alignment	The lateral deviation of each rail from a reference line.
Profile	The vertical deviation of each rail surface from a theoretical reference line.
Cross Level	The difference in height between rails in a plane perpendicular to the direction of travel.

The profile and alignment data can also be printed out in terms of a 62-foot midchord to allow evaluation of track relative to the FRA standards. (See Subsection 1.1.1.)

The TGMS provides data using speed, distance traveled, and location detectors. Distance data are obtained using a Rotary Pulse Generator (RPG) and vehicle location is obtained using an Automatic Location Detector (ALD). These data are used as reference data when processing the speed, gage, alignment, profile, and cross level parameters. (See Subsection 1.1.2 for a detailed explanation of the reference data detector system.)

The TGMS consists of three major subsystems: the sensor system, the data acquisition system, and the power supply system (see Figure 1-1). A description of the three subsystems follows.

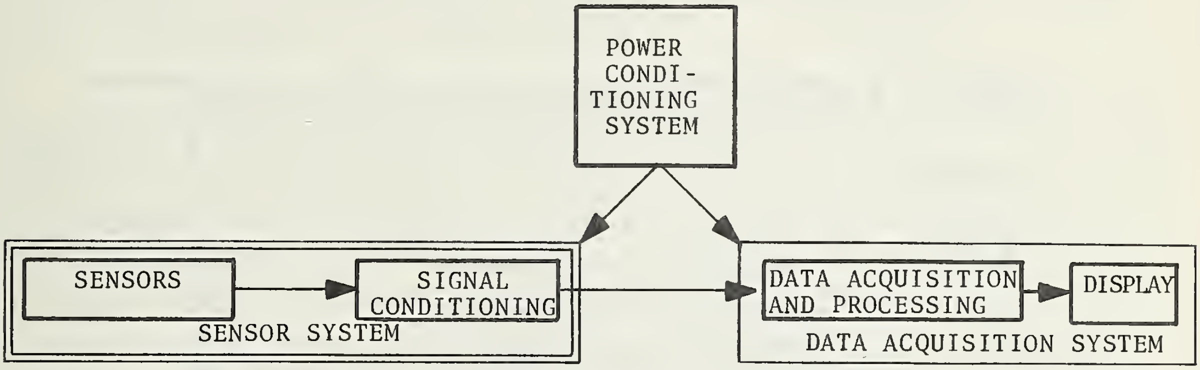


FIGURE 1-1. TYPICAL TRACK GEOMETRY MEASUREMENT SYSTEM

Sensor System

The sensor system provides raw data to an on-board acquisition system which calculates the speed and geometric parameters of the track, i.e., rail gage, profile, cross level, and alignment.

The TGM sensor system consists of 1g, 2g and 10g accelerometers to sense vertical acceleration of each of the two journal boxes on one axle; an optical sensor to locate the gage point of each rail with respect to a sensor beam; a 1g accelerometer to sense lateral acceleration of the sensor beam; an ALD probe to provide location reference marker pulses; and a rotary pulse generator to provide incremental data about axle rotation from which vehicle speed and distance traveled information can be calculated. (See Figure 1-2.) The 2g and 10g accelerometer data are not used in the TGMS calculations.

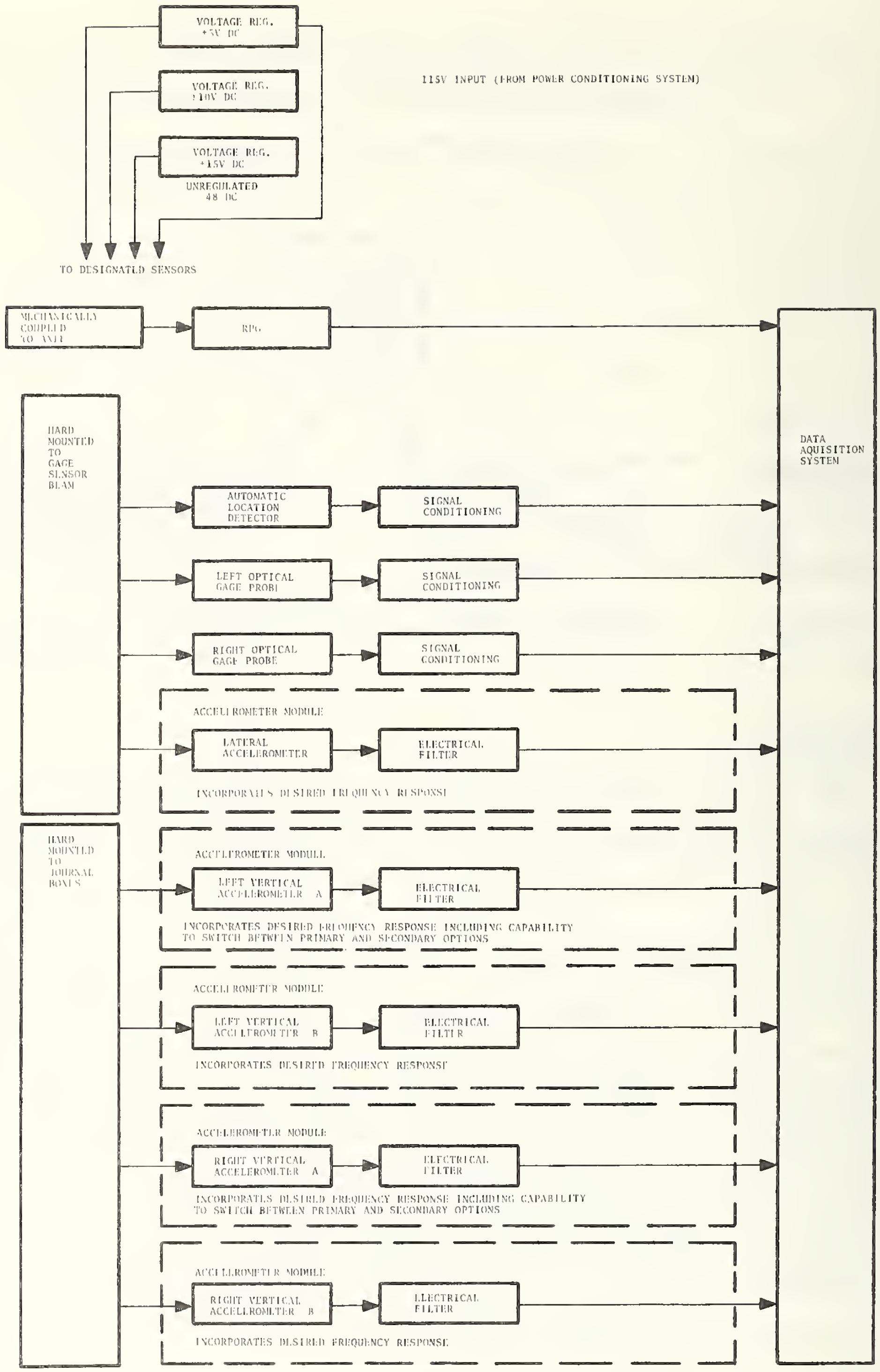


FIGURE 1-2. TRACK GEOMETRY SENSOR SYSTEM

Data Acquisition System

For handling the track geometry measurements quickly and economically, a Data Acquisition System (DAS) has been developed in conjunction with the Track Geometry Sensor System. The function of the DAS is real-time data acquisition processing and storage. (See Subsection 1.3 for more detail.)

The primary task of the central processor is a real-time collection of data from the analog-to-digital converter at a minimum data rate of 60 kilobytes per second, processing of the data, and storing of all the data on a bulk storage device. The central processor also has the capability to perform off-line data processing such as spectral analysis, auto- and cross-correlation, generation of histograms, and statistical processing. Output of the off-line processed data is in a format compatible with an eight-channel chart recorder or line printer.

The DAS consists of a UNIVAC 1616 computer, with a 24K memory module, a Datum 5091-U1616 Tape Transport Controller, two Bucode 4025 Tape Transports, the UNIVAC IOI, and two Zeltex Multiplexer/Analog-to-Digital Converters. Also included are a Teletype ASR-35 Teleprinter and a VERSATEC LP1150 Line Printer. Appendix A is a hardware description of the DAS and output devices.

Uninterruptable Power System

The Uninterruptable Power System (UPS) supplies constant voltage power. Power is normally taken from the third rail. If third rail power is interrupted, the UPS switches to battery power and maintains acceptable voltages. (See Subsection 1.3 for more information.)

1.1.1 Midchord Technique

Historically an indication of profile was obtained using a midchord measurement technique. This measurement was made by two men stretching a string along the rail and a third man measuring the distance from the midpoint of the string to the top of the rail.

This traditional measurement technique has been carried into the track standards defined by the Federal Railroad Administration (FRA).

Automated midchord-to-ordinate measurement schemes have been used recently. However, the chord length varies nearly as much as the number of systems, thus making comparison of data from different systems nearly impossible.

The direct measurement technique used in TGMS provides data that will satisfy the objectives of track measurement. The "true profile" data reproduces the actual vertical perturbations, over the wavelengths of interest, experienced by the trains. Presentation of track defects with high and low spots reported in terms of magnitude and location provides the essential information for carrying out repairs.

The method by which midchord offset profile and alinement are computed in the TGMS is described in Appendix B.

1.1.2 TGMS Measurement Techniques

The techniques incorporated into the TGMS for obtaining the four basic parameters of the track and reference data are described in the following paragraphs.

Optical Rail Gage Measurement

Track gage is measured by an electro-optical system. The technique works on the principle of illuminating the base of the rail and detecting the position of the shadow cast by the gage side of the rail head onto a photo detector array.

The optical components of each gage sensor are mounted on a rigid gage sensor beam, with one sensor located over each of the rails. It detects the position of a line tangent to the rail head and perpendicular to the top surface of the tie at the gage side of the rail head.

Currently, the system makes a gage measurement every 0.75 inch of travel for speeds between 0 and 60 mph. The sampling of gage measurements is accomplished on a distance basis.

The optical gage system is capable of measuring gage variations over the range of from 0.5 inch tight to 1.4 inches open with a repeatability of 0.01 inch.

Profile and Cross Level Measurement

Acceleration is a direct physical input into the rail vehicle operating on the track. Two pairs of accelerometers mounted on the same wheel/axle assembly sense the vertical acceleration of each wheel of the instrumented truck. Both accelerometers (A and B) are hard mounted on the unsprung portion of the journal and located as close to the axle as is possible so the measurement is made of the deflected track. Accelerometers A and B contain a dynamic range circuit (DRC) which reduces accelerometer sensitivity as frequency increases beyond some cutoff frequency. In the primary mode, accelerometer A measures linear acceleration in the range $\pm 0.002g$ to $\pm 2.0g$ in the frequency range of $f \leq 20$ Hz. The secondary mode allows for measurement in the range +0.001g to $\pm 1.0g$ for a frequency range of $f \leq 10$ Hz. Accelerometer B measures linear acceleration in the range of $\pm 0.01g$ to $\pm 10g$ in the frequency range $f \leq 100$ Hz.

Each accelerometer output signal is amplified and filtered electrically, and digitized for processing in the on-board data acquisition system (DAS). The DAS then performs a double integration with respect to time of the output of each "A" accelerometer to compute the deviation in the vertical position of each rail with respect to the moving reference.

The two pairs of accelerometers are mounted on the same wheel/axle assembly and the profile data for each rail is correlated to the same points along the track. This permits the generation of cross level data in the DAS by simply taking the arithmetic difference between the left and right profile data. Cross level is the algebraic difference, in inches, between the left and right profile measurement at vehicle speeds between 20 and 60 mph.

Alignment Measurement

The alignment measured by the subsystem is the lateral (horizontal) deviation of each rail with respect to some moving reference. The method by which the alignment of a rail is measured is as follows: An accelerometer for sensing lateral accelerations of the beam is hard mounted on the gage sensor beam. The beam is a rigid structure supported from an unsprung portion of the rail car truck assembly and located as close to the axle as possible to assure that the measurements are made of the deflected track. The output signal from the accelerometer is amplified and filtered electrically, and then digitized for processing in the DAS. The DAS performs a double integration with respect to time of the accelerometer signal to compute the lateral position of the gage sensor beam with respect to some moving reference. The lateral position of the gage sensor beam is then added to the distance from each rail to the reference point of its optical probe, to yield the distance from each rail to the moving reference.

Automatic Location Detector

The automatic location detector (ALD), an inductive sensor, is responsive to the physical features found between the rails such as switches, guard rails or metal plates. The signal from the sensor also provides a positive identification of the vehicle location as a function of time and the detected track feature.

The ALD sensor, located beneath the car and above a plane tangent to the top surface of the rail heads at a position midway between the two rails, is designed to detect track features at vehicle speeds of 0 to 80 mph. In this speed range the maximum location measurement uncertainty with respect to the target surface detected is less than 1.0 inch.

Distance Detector

Distance is a basic reference parameter which is measured by use of a rotary pulse generator mechanically coupled to the vehicle axle. The generator, an optical incremental encoder, produces

1000 pulses per revolution of the axle with a measurement accuracy of 10 minutes of arc with respect to the leading edge of the pulse. The distance parameter is important in track geometry measurement, since it provides an accurate means of locating a particular track anomaly.

1.2 DATA ACQUISITION SYSTEM AND OUTPUT DEVICES

1.2.1 Data Acquisition System

The Data Acquisition System (DAS) converts all signals to digital equivalents, provides data acquisition, documentation, real-time and post-test processing, and interfacing for input/output devices.

The DAS, as developed for the Rail Technology Test program at the Transportation Test Center (TTC), Pueblo, Colorado, has been designed for three major functional applications using essentially the same equipment, the variations of which are designated as DAS-1, DAS-2, and DAS-3. The system can also be utilized for tests or demonstrations on transit properties.

DAS-1 is for vehicle testing, interfacing with conditioned and filtered signals from a set of general sensors, according to the General Vehicle Test Plan.

DAS-2 is a reduced version of the DAS-1, with most components interchangeable. DAS-2 is mounted in a mobile test van to be used at any of the eight wayside test stations at TTC. The data collected from these stations are to be time-correlated with the vehicle data of DAS-1.

DAS-3 is identical to DAS-1. The assigned purpose of DAS-3 is employment with the Track Geometry Measurement System, to provide real-time computations of the desired track parameters.

Main Components

The block diagram (Figure 1-3) outlines the DAS main components. The block to the left of the dashed line represents the sensors and analog signal conditioners, totalling up to 32 instruments,

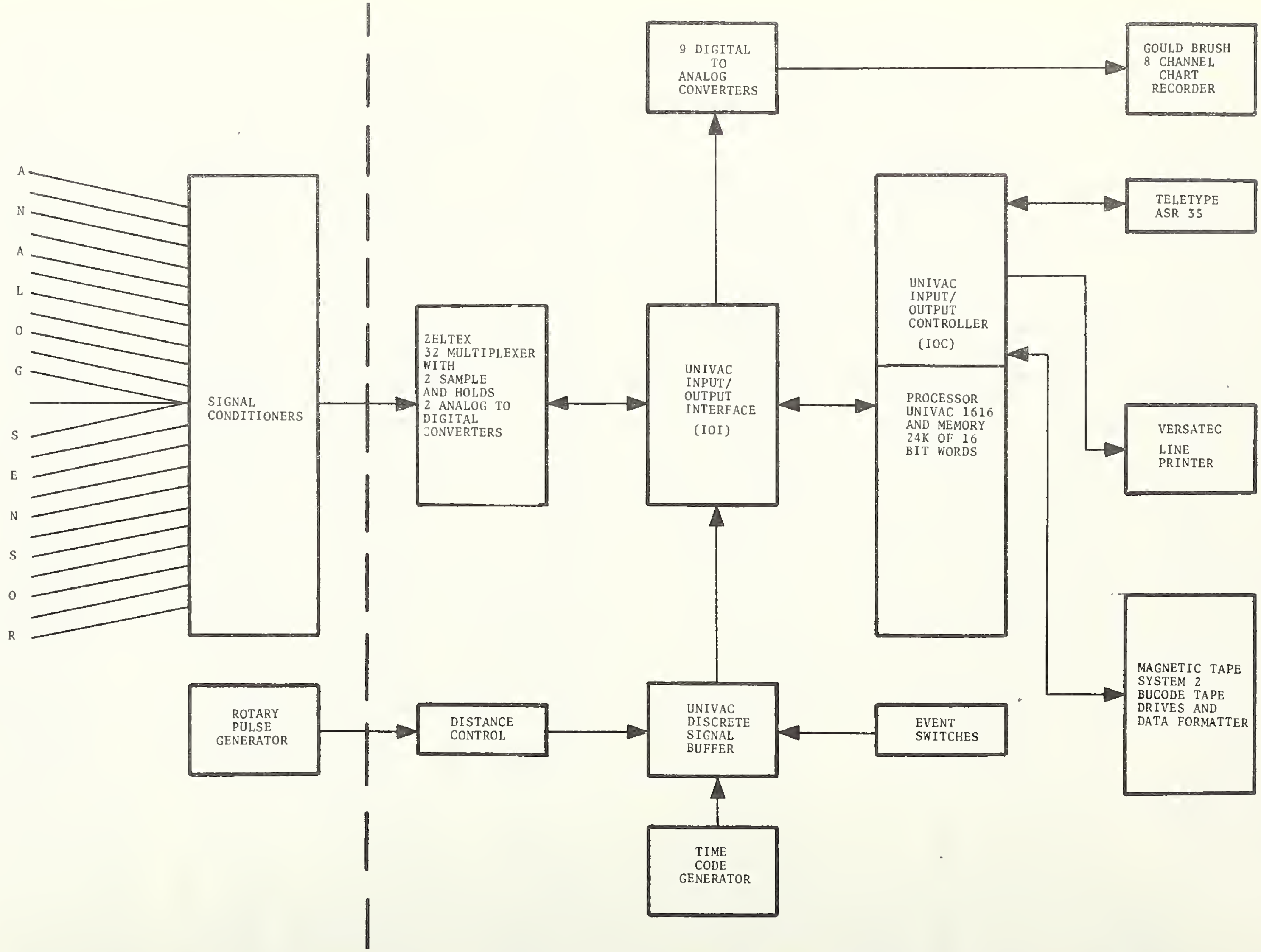


FIGURE 1-3. DATA ACQUISITION SYSTEM BLOCK DIAGRAM

the inputs of which become filtered, amplified, and referenced to the Multiplex Unit. In addition to analog signals, the Conditioning Unit can enter digital signals, or discrete pulses, into the computer via the Discrete Signal Buffer.

The functional computing and processing equipment with accessories consists of the following units:

a. The UNIVAC 1616 Digital Computer consists of a central processor, a memory containing 24K of 16-bit words, and an Input/Output Controller channel. Memory capacity can be expanded in 8K increments to a total of 64K. All memory modules are directly addressable.

b. The Digital-to-Analog Converters (DAC) accept computer information as control words and data words from the UNIVAC I/O Controller. The control words are used to address the nine DAC's and to channel 8-bit data bytes to the addressed DAC.

c. The Analog-to-Digital Converter (ADC) is a Zeltex 721 Multiplexer containing two 16-channel multiplexer modules with two sample and holds controlled by a sequencer module. The unit uses the successive approximation technique for comparing analog data with a stable voltage reference.

d. The UNIVAC Discrete Signal Buffer (Input/Output Interface) connects the I/O Controller (IOC) with up to eight discrete devices, each device providing 16 data bits to the I/O Controller. Appendix C describes the modifications to the IOI such that asynchronously timed inputs are interfaced to the controller and a priority of interrupts is established. The unit is used to input data from the Time Code Generator, the Distance Control, and the Event Switches.

1. Datum 9300 Time Code Generator produces a very accurate 1 MHz signal and a binary coded decimal representation of the time of day in hours, minutes, and seconds, thus providing time reference data for all tests.

2. The Distance Control accepts pulses from a rotary pulse generator, passing them into the computer as 16-bit words

denoting distance traveled. It also provides time and speed references by counting time between pulses and providing a 16-bit speed word input.

3. The Event Switches provide the third input to the Discrete Signal Buffer, being remotely controlled by test personnel. These switches serve as 16 toggle-operated sampling and computer-interrupt provisions.

1.2.2 Data Output Devices

The Data Output Devices provide digital magnetic tape records of raw and processed data, real-time stripcharts, and printouts. (See Appendix A for a detailed description of data output devices.)

a. The Line Printer is a VERSATEC Matrix LP1150 unit that prints computer-provided data, accepting synchronous coded data in series from the Input/Output Controller (IOC). It converts codes to characters by using a Read Only Memory.

b. The Magnetic Tape System (Bucode 4025) uses its data storage and retrieval facilities to provide the DAS bulk storage capability. The unit is an industry-standard NRZI 9-track transport with a reading and writing speed of 100 ips. The unit also contains a Datum formatter.

c. The Gould Brush 481 Chart Recorder is an incremental drive with eight signal channels and one timing channel fed by the DAC. The recorder uses the pressurized ink writing technique over a 40mm wide graph for each signal channel. The timing channel utilizes 4mm between channels 1 and 2.

d. Automatic Send/Receive (ASR) 35 Teletypewriter serves to record information received from a signal line as a code combination of characters and functions. The unit translates code combinations into mechanical motions imprinting a message or initiating a function.

1.3 UNINTERRUPTABLE POWER SYSTEM

The Uninterruptable Power System (UPS) (Figure 1-4) converts the raw 600 VDC power from the third rail to regulated 115 VAC, 60 Hz power used by the Data Acquisition System (DAS) and the Track Geometry Sensor System (TGSS). If third rail power should be interrupted, the Ni-Cd battery in the UPS will maintain the 10 kVA rated output for 10 minutes. The output voltage of 115 VAC, 60 Hz is thus maintained within tolerance during interruptions of the 600 VDC power source to prevent power surges to the DAS and TGSS.

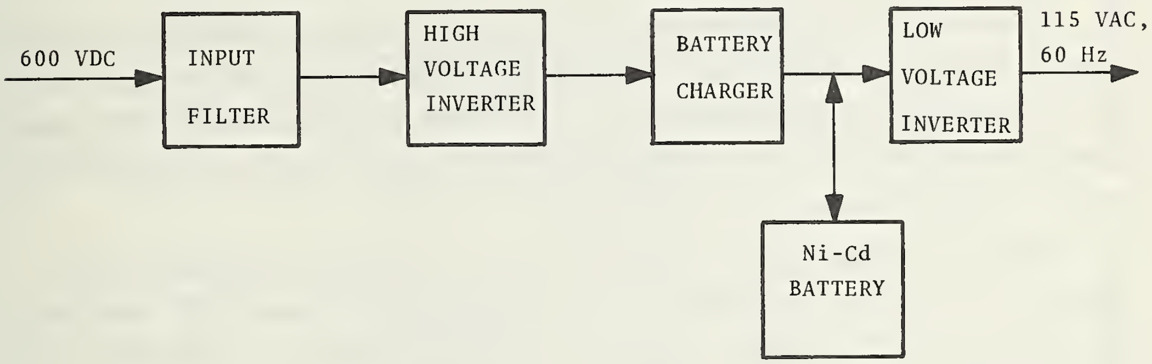


FIGURE 1-4. UNINTERRUPTABLE POWER SYSTEM BLOCK DIAGRAM

1.4 SOFTWARE OVERVIEW

TGM6C, the TGMS real-time software, accepts input records that are stored in designated portions of core prior to program loading. There are two input records, a header record and a parameter record. Program HEADER generates the header record from teletype inputs then calls TRAIN to generate the parameter record from the header record.

TGM6C initializes variables, and outputs the header record onto the output tape. The initial Automatic Location Detector (ALD) pulse closes the electronic switch that permits Rotary Pulse Generator (RPG) interrupts to provide a sequence of reference points. The program completes a processing cycle every eight RPG interrupts.

The processing done between every RPG interrupt is a minor cycle. Some tasks are performed every minor cycle whereas the remaining tasks are spread among the eight consecutive minor cycles.

The raw and processed data are channeled to output buffers and stored on magnetic tape when the buffers are full. The processed data is also output through the input/output interface to the D/A Converter to a chart recorder. The system has an option available that allows the program to use a data tape as input rather than reading the A/D's.

Figure 1-5 gives an overview of the hardware/software data handling.

The sensor system includes the gage cameras, automatic location detector, lateral accelerometers, the rotary pulse generator, and the vertical accelerometers. The raw accelerometer and gage data are processed by the signal conditioners and A/D converters before being channeled to the DAS.

The DAS inputs gage data (OL, OR) and accelerometer data (ALATR, AVL, AVR) into the A/D Converter and inputs RPG and ALD into the Discrete Signal Buffer. The RPG pulses are divided by a pre-setable number n and generate an interrupt every n pulses. Event switch settings and time reference data from the time code generator are input to the discrete signal buffer which outputs to the DAS.

The DAS software is cued by the RPG interrupt and begins processing when it is received. The A/D's are sampled to get OL, OR, ALATR, AVL, and AVR. The discrete signal buffer is sampled to get DT (the time between two RPG interrupt pulses), and ALDEV (a word with the ALD bit and the event switch settings). The accelerometer inputs are doubly integrated to get lateral beam position (BP) and left, and right profile (PL, PR). Gage (G), speed (VS), cross level (XL), and left and right alignments (AL, AR) are calculated. The ALD bit is stripped and processed for storage and chart recorder output. The processed data is output on the chart recorder. Raw and processed data are stored on magnetic tape for future analysis.

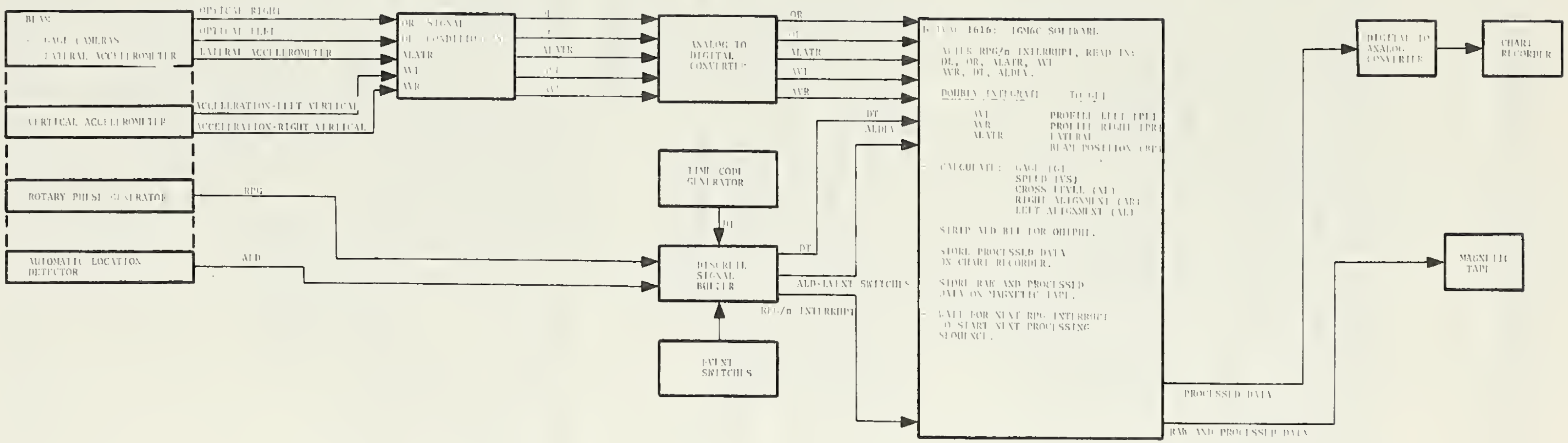


FIGURE 1-5. HARDWARE/SOFTWARE DATA HANDLING FLOW DIAGRAM

2. TGM6C DATA FLOW AND HANDLING

2.1 INTRODUCTION

TGM6C is a data collection and reduction software system. The primary purpose of this program is to collect track geometry data, perform required data reduction, and output the results to a storage device. This section describes the data flow sequence, the sampling sequence, the output mangetic tape record format, delayed brush recorder output, and major core storage requirements. These sequences and procedures were developed specifically for the Track Geometry Measurement System to condition the track variables making them acceptable to the Data Acquisition System (DAS).

2.2 DATA FLOW

The data flow chart (Figure 2-1) and the accompanying definition of variables (Table 2-1) depicts the data flow through TGM6C system. The input variables are shown as they are recorded from the sensors and processed by various subroutines and finally output. The chart is not time sequenced.

2.3 TGM6C SAMPLING SEQUENCE

The sampling rate of the TGM6C system is a major cycle for each 6 inches of travel. Each major cycle has eight minor cycles, i.e., an interrupt from the RPG counter is serviced every 0.75 inch of travel. This interrupt must be a priority interrupt and should not vary in the time it takes to service the interrupt by more than two machine cycles or 1.5 microseconds.

The sequence of sampling is as follows:

First Minor Cycle (1st MC)

DT, OL, OR, HAVL, HAVR

AVL, AVR

ALATR, ALDEV

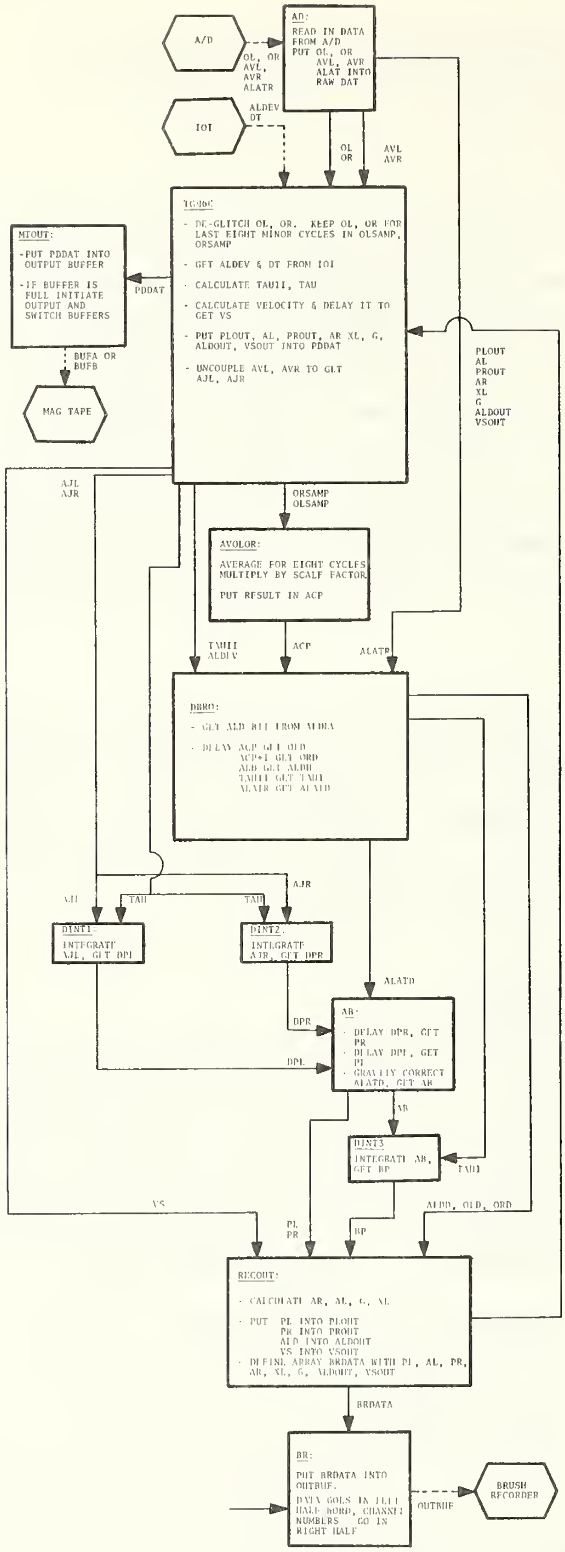


FIGURE 2-1. DATA FLOW CHART

TABLE 2-1. TGM6C PROGRAM DEFINITION VARIABLES

Term	Definition
AB	Beam lateral acceleration
ACP	Array with two values. The first value is average of OL for last eight minor cycles and the second value is an average of OR for last eight minor cycles.
AJL	Left journal vertical acceleration
AJR	Right journal vertical acceleration
AL	Left alignment
ALATD	Lateral acceleration delayed
ALATR	Acceleration, lateral accelerometer signal
ALDD	Automatic location detector signal delayed
ALDEV	Input from IOI with ALD in bit 15 and event switch settings in rest of word
ALDOUT	ALD scaled for chart recorder
AR	Alignment right
AVL	Acceleration, vertical left accelerometer signal
AVR	Acceleration, vertical right accelerometer signal
BP	Beam lateral position
BRDATA	Array with brush recorder outputs in left half word
BUFA	Magnetic tape output buffer
BUFB	Magnetic tape output buffer
DPL	Double precision profile left
DPR	Double precision profile right
DT	Time between two RPG interrupts. LSB is 10 micro-seconds

TABLE 2-1. TGM6C PROGRAM DEFINITION OF VARIABLES (Continued)

Term	Definition
G	Gage scaled for chart recorder
HAVL	Acceleration vertical left accelerometer B signal (see Section 1.1.2)
HAVR	Acceleration vertical right accelerometer B (see Section 1.1.2)
OL	Left optical gage probe signal
OR	Right optical gage probe signal
OLD	Left optical signal after averaging and delay
ORD	Right optical signal after averaging and delay
OLSAMP	Array with last eight OL samples
ORSAMP	Array with last eight OR samples
OUTBUF	Brush recorder output array
PDDAT	Array of processed data to be put into magnetic tape output buffer
PL	Profile left after delay
PLOUT	Profile left scaled for chart recorder
PR	Profile right after delay
PROUT	Profile right scaled for chart recorder
TAU	TAU1I/2
TAU1I	Sum of DT's for last eight minor cycles
TAU1	Delayed value of TAU1I
VS	Velocity delayed
VSOUT	Velocity scaled for brush recorder
XL	Cross level scaled for brush recorder

2nd MC

DT, OL, OR, HAVL, HAVR

3rd MC

DT, OL, OR, HAVL, HAVR

4th MC

DT, OL, OR, HAVL, HAVR

5th MC

DT, OL, OR, HAVL, HAVR

AVL, AVR

6th MC

DT, OL, OR, HAVL, HAVR

7th MC

DT, OL, OR, HAVL, HAVR

8th MC

DT, OL, OR, HAVL, HAVR

This completes the major cycle which can be repeated by starting the 1st MC. The total input sample rate for raw data is 92 s/ft. The minor sampling cycle is based on 16 cycle/ft. Table 2-2 gives the task distribution among the eight minor cycles.

2.4 OUTPUT MAGNETIC TAPE RECORD FORMAT

The first four records are header records. They are all identical and are copies of the header generated by program HEADER.

The fifth record starts the data records. Each data record holds approximately 25 feet of data. The first 10 words of each record are the record introduction. The next 2300 words are raw data and the last 300 words are processed data.

Data Record

10 Word Intro.	2300 Words Raw Data	300 Words Processed Data

TABLE 2-2. MINOR CYCLE TASK DISTRIBUTION

Minor Cycle Task	1	2	3	4	5	6	7	8
Sample Δt	✓	✓	✓	✓	✓	✓	✓	✓
Sample OL	✓	✓	✓	✓	✓	✓	✓	✓
Sample OR	✓	✓	✓	✓	✓	✓	✓	✓
Sample HAVL	✓	✓	✓	✓	✓	✓	✓	✓
Sample HAVR	✓	✓	✓	✓	✓	✓	✓	✓
Sample AVL	✓				✓			
Sample AVR	✓				✓			
Sample ALAT	✓							
Sample ALD-EVENT	✓							
Sum Δt		✓						
Calculate Speed					✓			
Uncouple AVL, AVR to get AJL, AJR & STORE		✓			✓			
Average OL, OR→STORE	✓							
Calculate Recorder Outputs						✓		
Output to Chart Recorder							✓	
Integrate AJL		✓				✓		
AJL Smoothing by MAS						✓		
Integrate AJR			✓				✓	
AJR Smoothing by MAS							✓	
Gravity Correction A.Lat→AB				✓				
Integrate AB to get BP & STORE				✓				
Check Mag Tape Buffer								✓
Output Raw Data to Buffer	✓	✓	✓	✓	✓	✓	✓	✓
Output Processed Data to Buffer								✓
Increment RPG Count	✓	✓	✓	✓	✓	✓	✓	✓
Go to Interrupt Wait Loop	✓	✓	✓	✓	✓	✓	✓	✓
Delay PL,PR				✓				
Delay OL,OR,ALD,ALATR,TAU1					✓			
Deglitch OL,OR	✓	✓	✓	✓	✓	✓	✓	✓
Reset RPG	✓	✓	✓	✓	✓	✓	✓	✓

2.4.1 Introduction Format

Word 1: Record number starting with 0.

Word 2:
Word 3: Integer double precision binary count of number of RPG interrupts received by program at start of record.

Word 4: Elapsed time at start. (See Appendix C.)

Word 5: Elasped time at start. (See Appendix C.)

Word 6: Event switch. (See Appendix C.)

Word 7: Number of words raw data

Word 8: Number of words processed data

Word 9: Last data record indicator

0 - Not last record

1 - Last record

Word 10: Midchord-true profile indicator

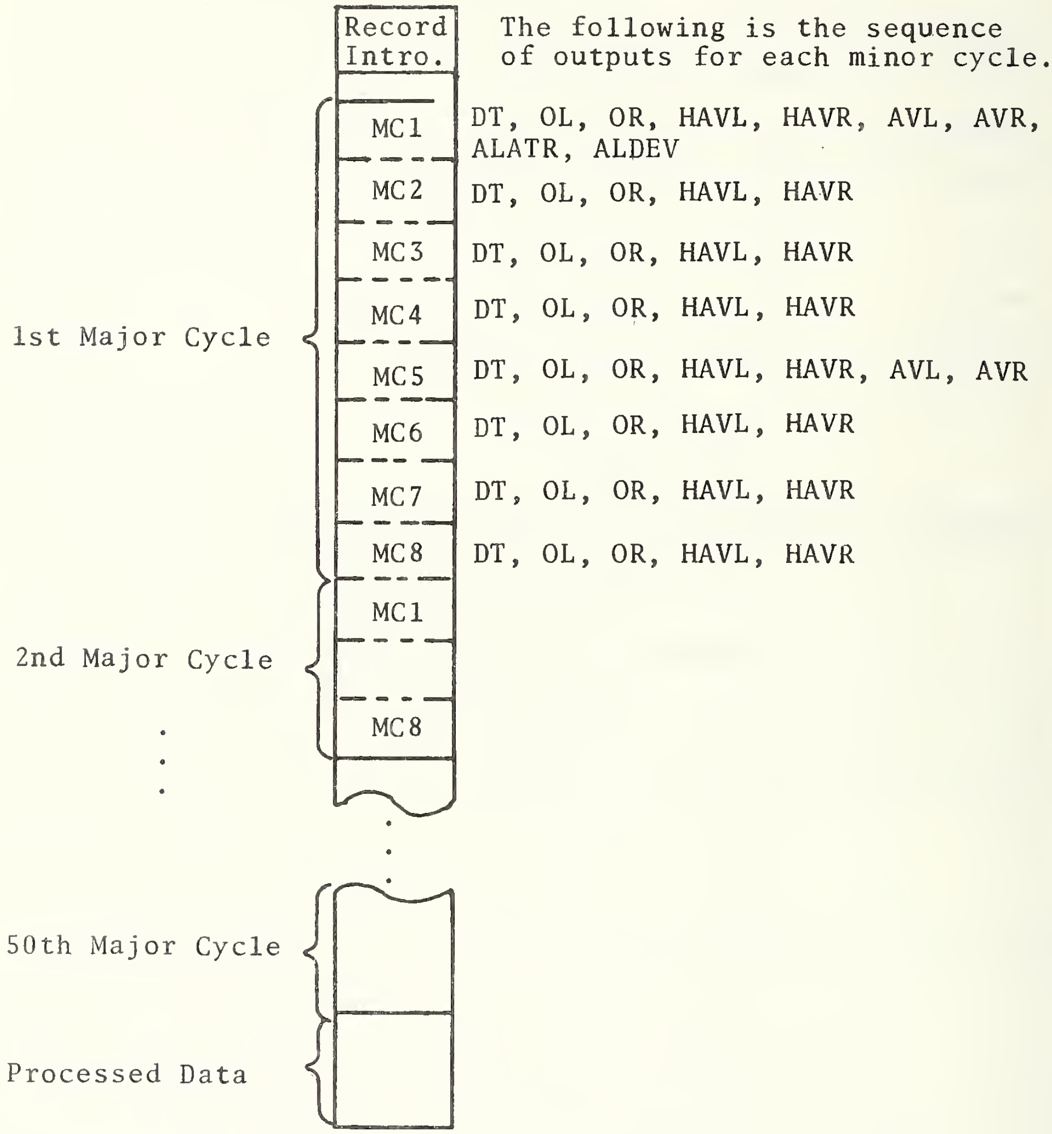
0 - True profile and alinement.

1 - Midchord profile and alinement.

2 - Both with no alignments.

2.4.2 Raw Data Format

The raw data is stored in the same sequence as it is read in. (See Section 2.3.) The 2300 words of raw data correspond to 50 major cycles or about 25 feet of track.



2.4.3 Processed Data Format

The processed data saved on magnetic tape is the same data that is output ot the chart recorder. Each major cycle outputs 6 words so that 50 major cycles will fill the 300 words of processed data in each record.

Word 1	VS	PL
Word 2	PR	XL
Word 3	AL	
Word 4	AR	
Word 5	G	
Word 6	ALDEV	

2.5 TGM6C DELAYED BRUSH RECORDER OUTPUT

To properly align all track variables they must be buffered for an appropriate distance. Because of the MAS buffer in the double integration routines and gravity correction caused by lateral acceleration, the brush recorder output displays track condition λ feet behind the track, where λ is the length of track for which there is data in the MAS buffer. To explain this buffering define P_1, P_2, P_3, P_4, P_5 to be points $\lambda/2$ distance apart. (See Figure 2-2.)

If data gathering begins at P_1, then λ distance later at P_3 the MAS buffers in the profile integration routines are filled and profile (PL, PR) may be calculated at P_2. At P_2 begin filling the ALATR delay buffer lateral accelerometer. It will be filled λ distance later at P_5. At this point beam position (BP) may be calculated for P_3. Since P_3 is λ distance behind P_5, all variables must be delayed λ distance behind the input sensors.

Figure 2-2 illustrates initial buffer filling and the delays necessary for various outputs.

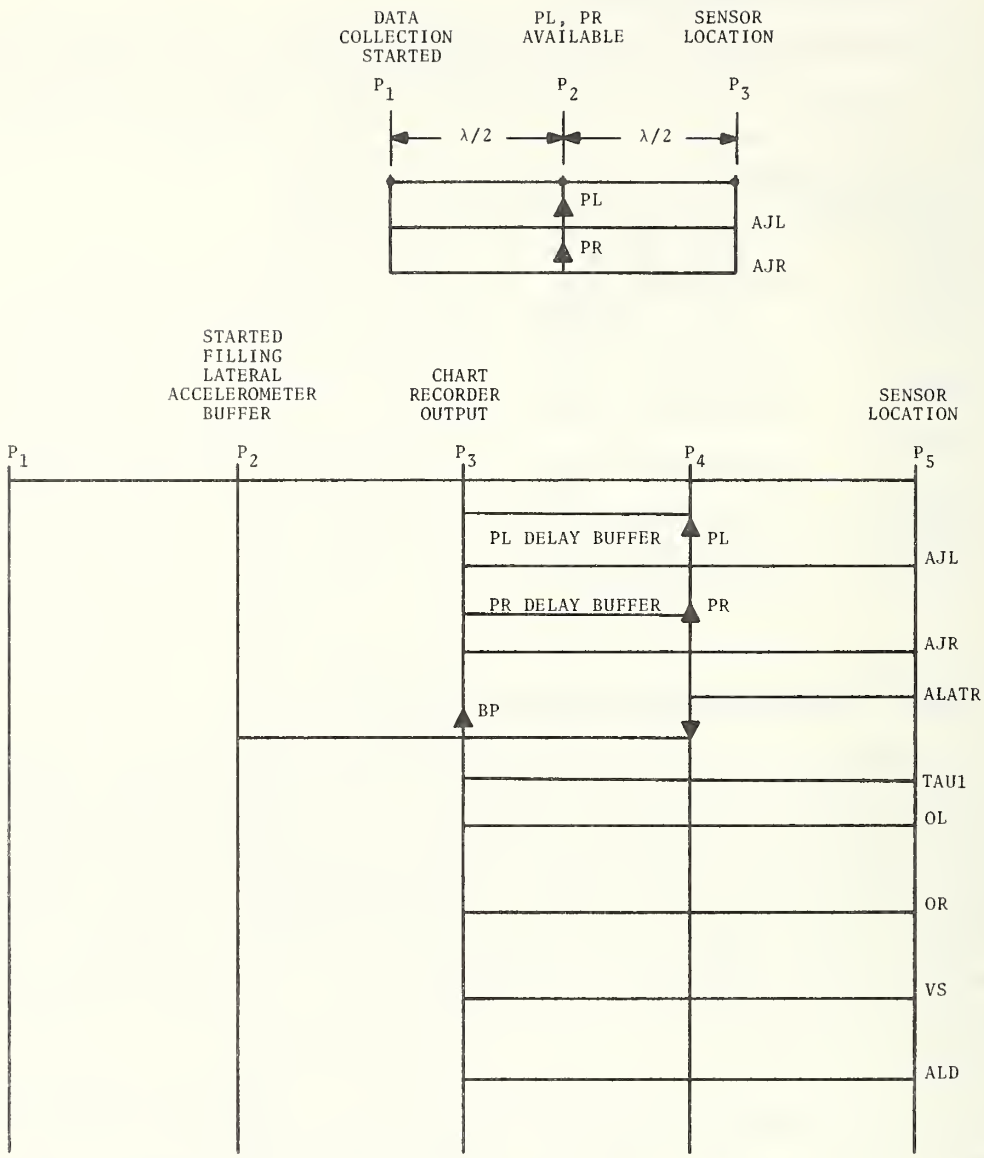


FIGURE 2-2. DELAYED BRUSH RECORDER OUTPUT

2.6 MAJOR CORE STORAGE REQUIREMENTS

The major core storage requirements are based on a maximum MAS buffer of 150 ft. In TGM6C buffer space is defined for 150 ft, however only 64 ft is being used. The major core storage requirements of Figure 2-3 are shown in Table 2-3.

Table 2-4 lists the raw and processed data with sample rates, accuracy and chart recorder, and magnetic tape output requirements.

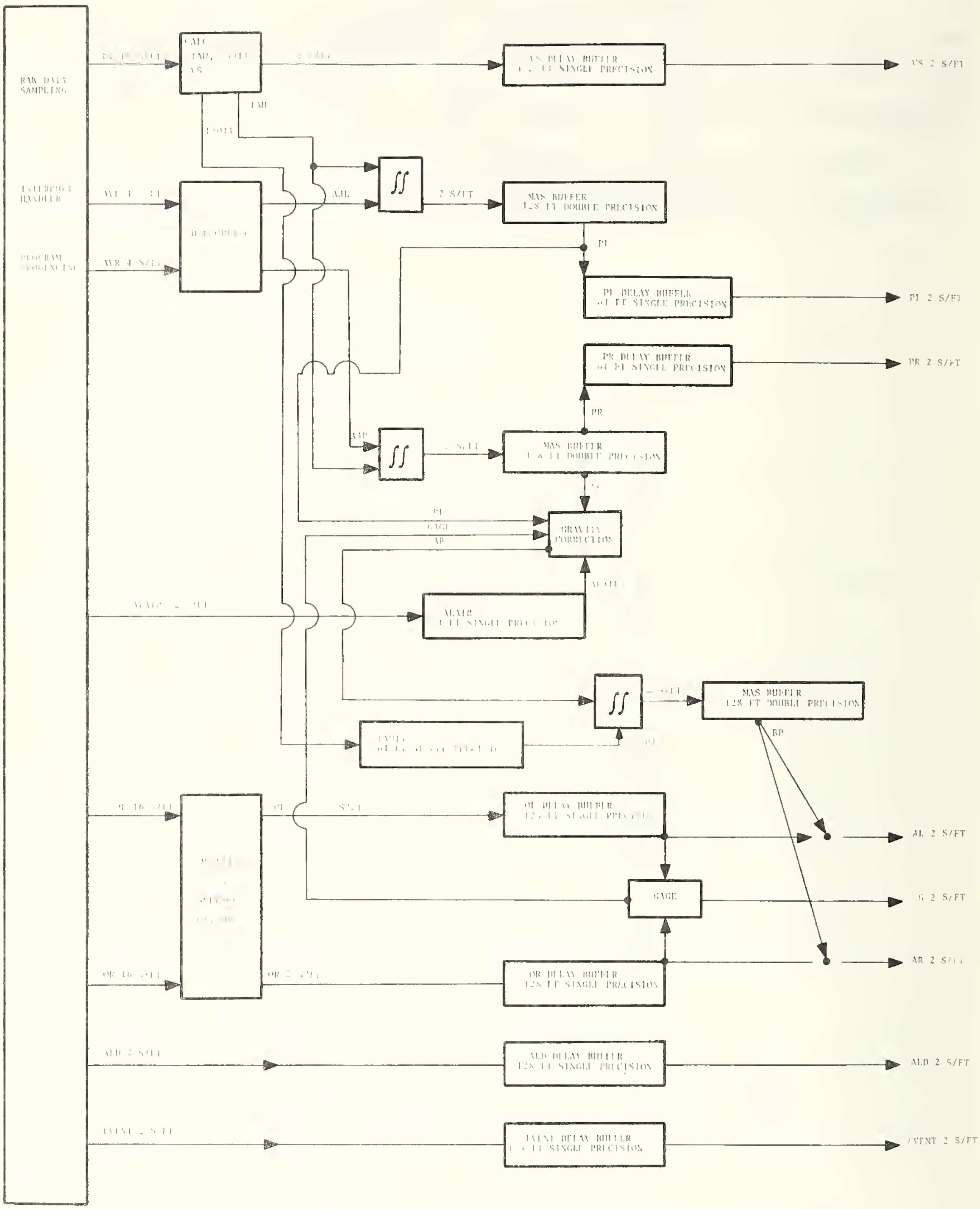


FIGURE 2-3. CORE STORAGE REQUIREMENTS FLOW DIAGRAM

TABLE 2-3. MAJOR CORE STORAGE REQUIREMENTS

Type	Length (ft)	Precision	Sample Rate (s/ft)	Core Words
VS	128	Single	2	300
AJL	128	Double	2	600
PL	64	Single	2	150
AJR	128	Double	2	600
PR	64	Single	2	150
AB	128	Double	2	600
ALATR	64	Single		150
OL	128	Single	2	300
OR	128	Single	2	300
ALD	128	Single byte	2	150
Event Mark	128	Single byte	2	150
TAU1I	64	Single	2	150
			Total	3,600

TABLE 2-4. RAW AND PROCESSED DATA PROCESSING REQUIREMENTS

Type	Sample Rate (s/ft)	Sample Size (bits)	Output Requirements	
			Chart Recorder	Mag Tape Recorder
Time	16	16		
OL	16	16		
OR	16	16		
HAVL	16	16		
HAVR	16	16		
AVL	4	16		
AVR	4	16		X
ALATR	2	16		X
ALD (raw)	2	8		X
Event Switches	2	8		X
Speed	2	8	X	X
PL	2	8	X	X
PR	2	8	X	X
XL	2	8	X	X
AL	2	16	X	X
AR	2	16	X	X
G	2	16	X	X
ALD delayed	2	8	X	X
Event Switches Delayed	2	8	X	X

3. HEADER/TGM6C PROGRAM INTERFACE

Two programs necessary for data gathering are HEADER and TGM6C. Figure 3-1 is a logic flow diagram of the HEADER/TGM6C interface. HEADER is run before TGM6C and provides TGM6C with a header array and a parameter array. The header array provides archival information and is copied by TGM6C onto the output tape. The parameter array passes numbers needed by TGM6C to process data.

TRAIN is a subroutine called by HEADER to generate the parameter array from the header array.

After HEADER has been run, the header and parameter arrays may be stored on tape for later use, or TGM6C may be run. If they are to be stored, they are copied onto magnetic tape in bootstrap format and booted back into the same locations from which they were retrieved.

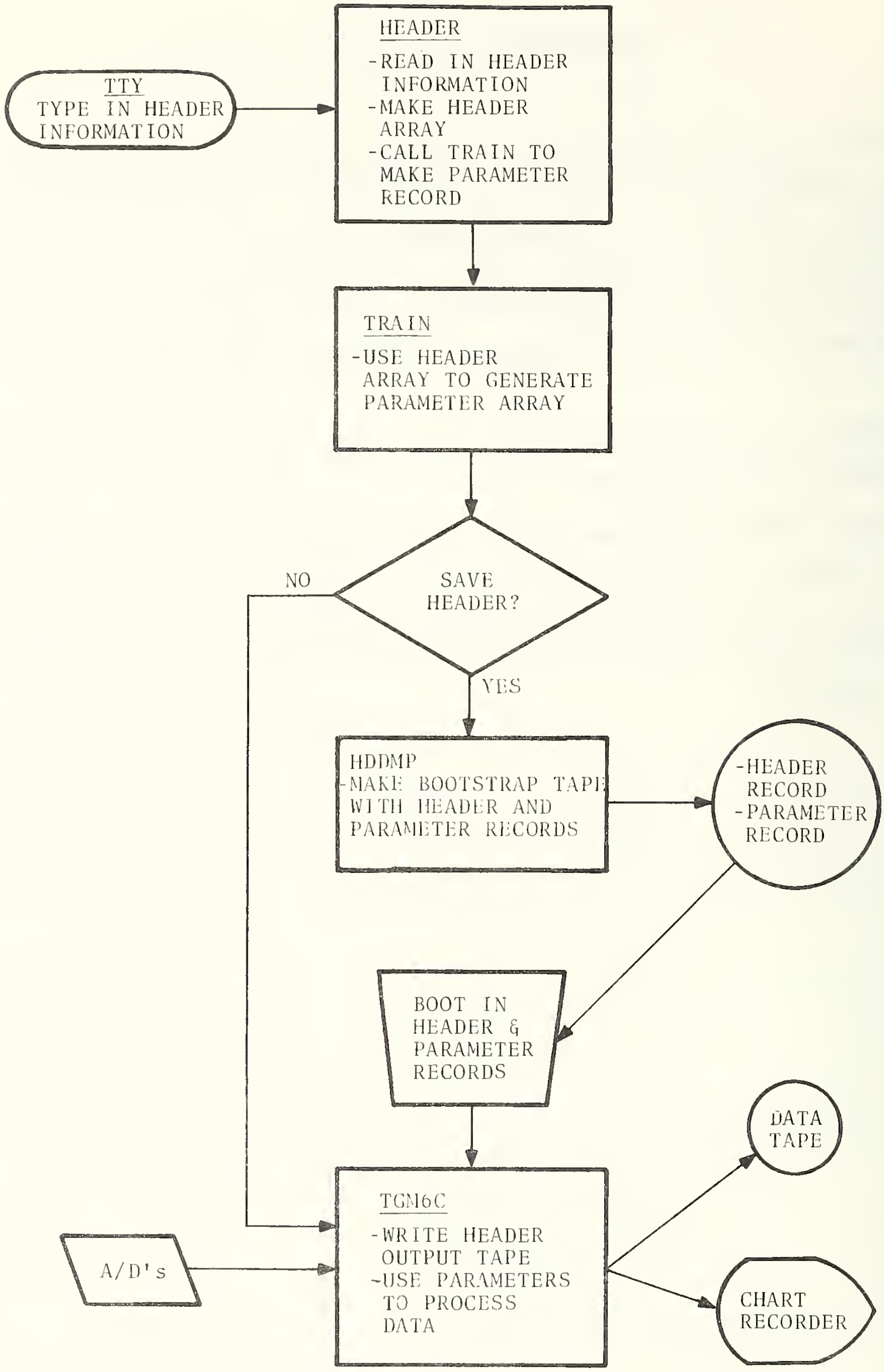


FIGURE 3-1. HEADER/PARAMETER GENERATION AND HEADER/TGM6C INTERFACE

4. TGM6C PROGRAM AND RELATED SUBROUTINE DESCRIPTIONS

The TGM6C program is divided into five sections: TGM6C, S1, S2, S3, and S4.

TGM6C is the system controller and contains the initializing variables and interrupt routines

S1 contains the input routines for A/D conversions and the output routines for magnetic tape and chart recording.

S2 contains coding to enable TGM6C to read in raw data from magnetic tape rather than from A/D converters. This option modifies the program such that, when activated, it will not accept A/D input.

S3 contains data processing routines for output scaling and data alignment and delay.

S4 contains three double integration routines using the algorithm devised by P. Mengert. (See Appendix B.)

4.1 TGM6C PROGRAM

TGM6C is the system controller for data gathering and output. It sequences operations and calls subroutines from S1, S2, S3, and S4. (See Section 4.2.) This description follows Figure 4-1 and gives a time sequence description of the TGM6C program.

TGM6C begins by initializing variables and interrupt returns, and recording the header record on magnetic tape four times. The program then halts until the train moves into position. Continuing execution causes the program to execute a wait loop.

The first ALD after the program is initialized allows RPG interrupts to be generated and data processing to begin. The first three interrupts are used to provide a valid DT (time between two RPG interrupts) at the beginning of data processing.

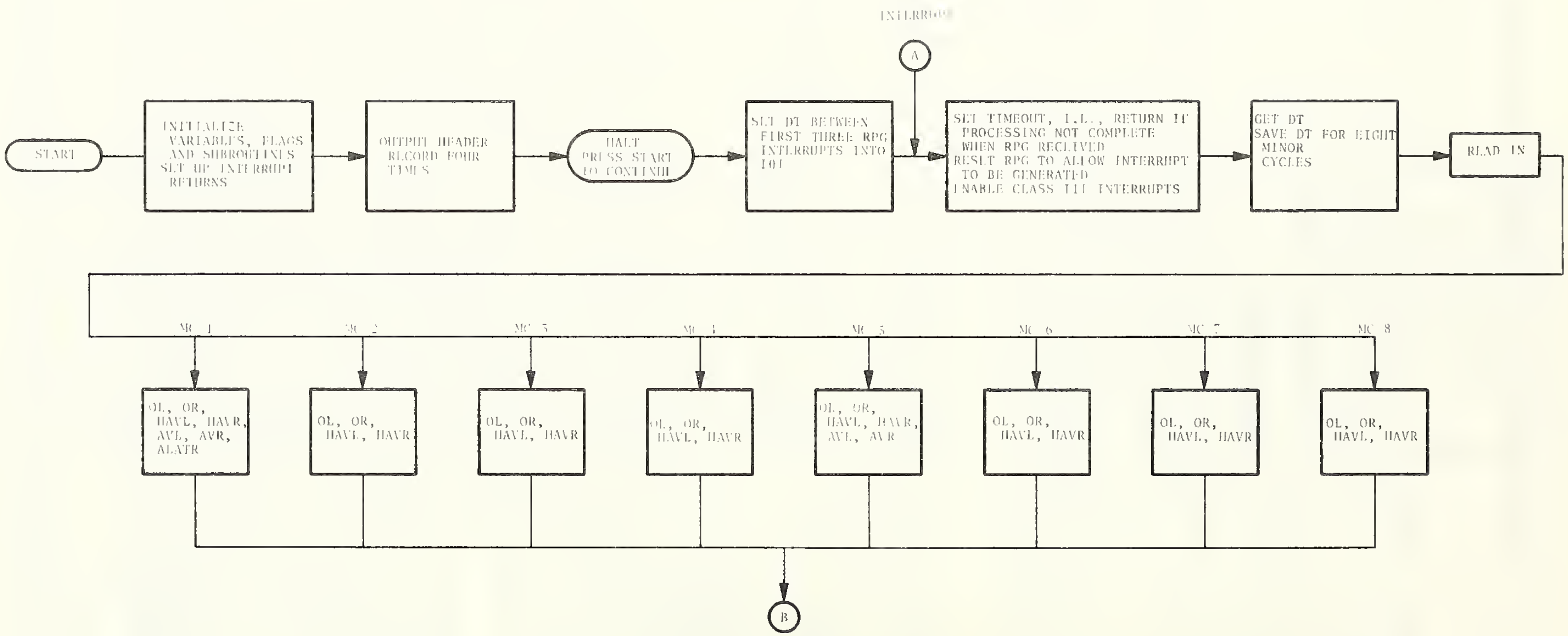


FIGURE 4-1. TGM6C FLOW CHART (SH. 1 of 3)

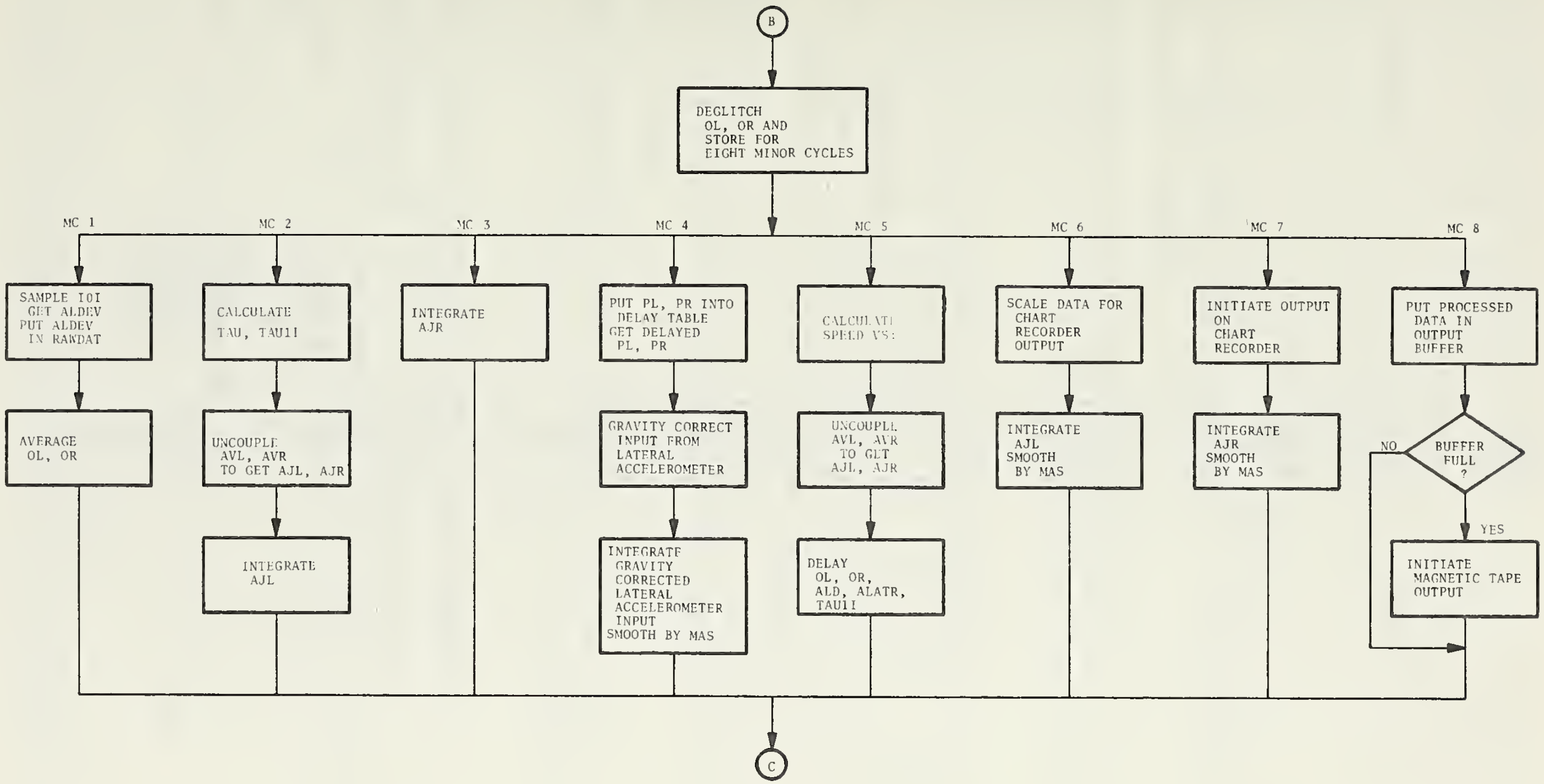


FIGURE 4-1. TGM6C FLOW CHART (SH. 2 of 3)

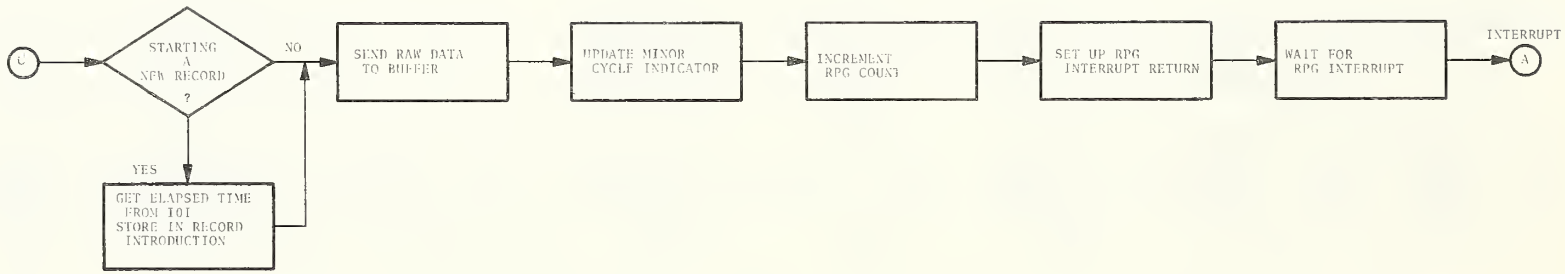


FIGURE 4-1. TGM6C FLOW CHART (SH. 3 of 3)

The program then begins the main data processing loop. The RPG interrupt return address is set to halt at location 0670. (See Section 5.3.F.) If an interrupt is received before processing is completed, the program halts. The RPG interrupt is then enabled.

The current DT is read in from the IOI. These times are saved for eight minor cycles. The time between eight RPG interrupts and between four RPG interrupts is calculated for input to the integration routines.

Accelerometer and gage data is input from the A/D's. The input data depends upon the particular minor cycle being read. (See Appendix D.)

Various processing and I/O tasks are spread over eight minor cycles. These eight minor cycles make up a major cycle and represent one complete processing cycle. The program branches to that part of the program that will process the current minor cycle. (See Table 2-2 and TGM6C Flow Chart, Figure 4-1.)

Minor Cycle 1 inputs the ALDEV (see Appendix C), stores it for output and averages the gage data OL and OR for the previous eight minor cycles.

Minor Cycle 2 calculates TAU and TAU1I for input to the integration routines, uncouples AVL and AVR, and integrates AJL. (See Appendix B.)

Minor Cycle 3 integrates AJR. (See Appendix B.)

Minor Cycle 4 delays PL and PR (see Section 2.5), gravity corrects the lateral accelerometer input ALATD (see Appendix E), and integrates and smoothes the gravity corrected lateral accelerometer input.

Minor Cycle 5 calculates speed VS, uncouples AVL and AVR (see Appendix F), and delays OL, OR, ALD, ALATR, and TAU1I. (See Section 2.5.)

Minor Cycle 6 scales the processed data for output on the chart recorder. (See Appendix G.) AJL is integrated and smoothed.

Minor Cycle 7 initiates output on the chart recorder of the data scaled in Minor Cycle 6. AJR is integrated and smoothed. (See Appendix B.)

Minor Cycle 8 outputs processed data scaled for the brush recorder into the processed data output buffer. (See Section 2.4.3.) If the output buffer is full, it is stored on magnetic tape.

After processing each minor cycle the program checks for the start of a new record. If a new record is being started, the elapsed time is read in from the IOI (see Appendix C) and stored in the record introduction. (See Section 2.4.1.) The raw data is stored in the output buffer. (See Section 2.4.2.) The minor cycle indicator is updated and the RPG count incremented. The RPG interrupt return is changed from an error return to a return to begin processing. The program then goes into a wait loop until the RPG interrupt sends it to the beginning of the main processing loop.

4.2 TGM6C SUBROUTINES

4.2.1 S1 Description

Subroutine S1 contains most of the input/output code for the TGM6C program. It performs the A/D input and magnetic tape and chart recorder output.

The A/D input routine (Figure 4-2) is initialized by calling ADINIT. ADINIT loads in the A/D subchannel assignments from the input perameters set up by HEADER. The subchannel assignments are put into arrays. Each minor cycle has its own array which contains the A/D input subchannels for that minor cycle. The subchannel assignments are put into the subchannel portion of the control word (Appendix C), and are used as external function control words.

The A/D's are sampled by calling routine AD. (See Figure 4-3.) The current minor cycle and the number of words to be read in this minor cycle are loaded from memory. The number of words to be

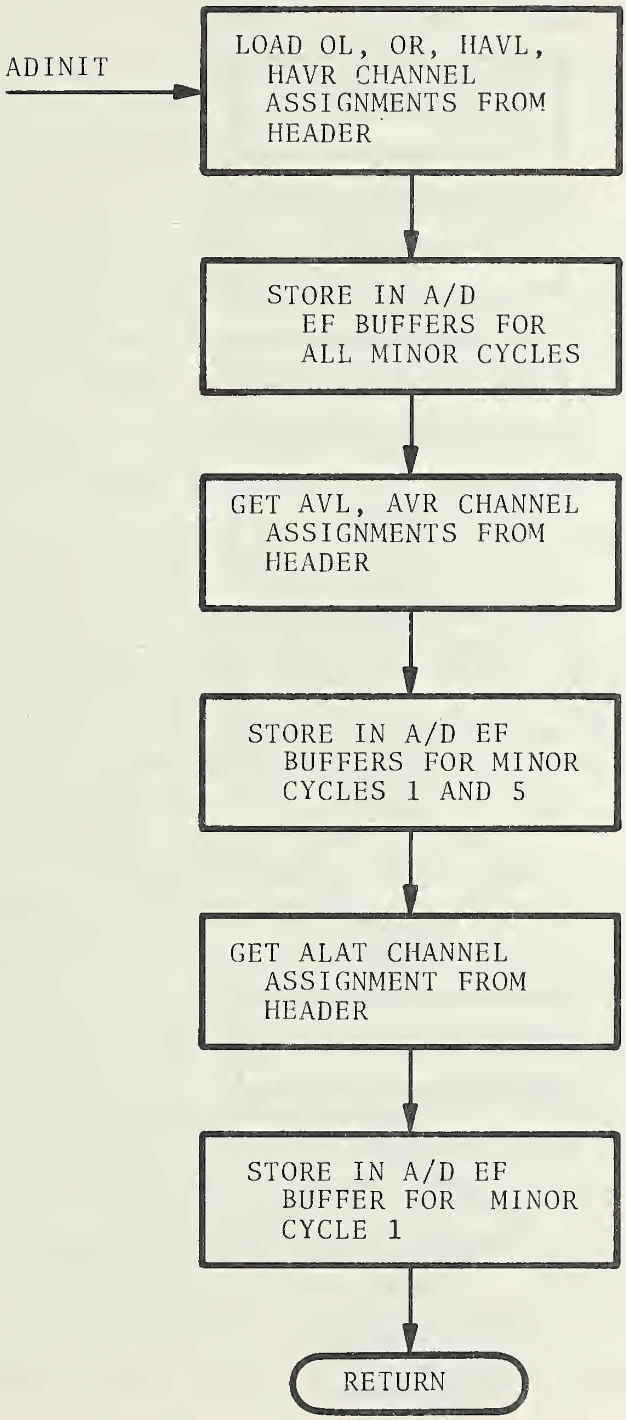


FIGURE 4-2. S1 A/D INPUT ROUTINE ADINIT

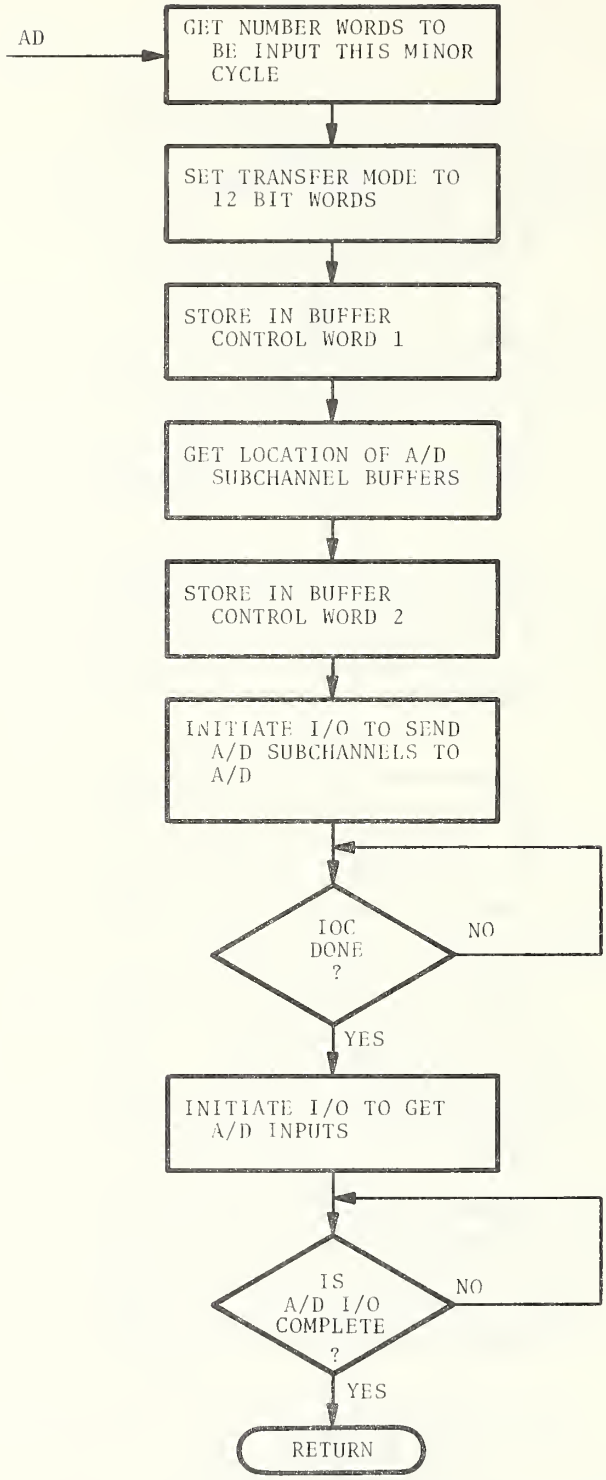


FIGURE 4-3. S1 A/D INPUT ROUTINE AD

read in is increased by one to give the total number of words RAWDAT will contain after the A/D's are read. (The time between two RPG interrupts (DT) is already in RAWDAT.) The input and output buffer control word 1 is generated by setting the transfer mode bit (See Figure 4-4 UNIVAC 1616 Technical Description) in the word containing the number of words read in.

The location of the array of subchannels to be sampled in this minor cycle is stored in external function buffer control word 2. Output is initiated to send the A/D subchannel designators to the A/D and input is initiated to read in the A/D data. When input is complete the routine returns.

The magnetic tape routine contains routines for initialization, data storage, and magnetic tape output.

The initialization routine MTINTL (Figure 4-4) sets up a series of four pointer arrays. Two pointer arrays are set up for each buffer, one for raw data and one for processed data. The arrays are zeroed out, then the first locations of the raw and processed data portions of each buffer are put into their corresponding pointer arrays. The full buffer flag is zeroed to indicate there is no buffer ready for output, and the number of RPG interrupts received is set to zero.

Data are stored on magnetic tape by calling routine MTDAT. (See Figure 4-5.) The program checks for raw or processed data. It then loads in the buffer switch to indicate which buffer is being filled and loads in the proper buffer pointer array.

If the buffer is full it switches buffers, sets a flag to indicate a buffer is ready for output, gets the RPG count and stores it in the buffer to be filled, and returns.

If the buffer is not full, a check is made for raw or processed data. The data is loaded in, an instruction to store the data in the proper location is generated, and the data is stored in the proper output buffer. The pointer arrays are updated and stored.

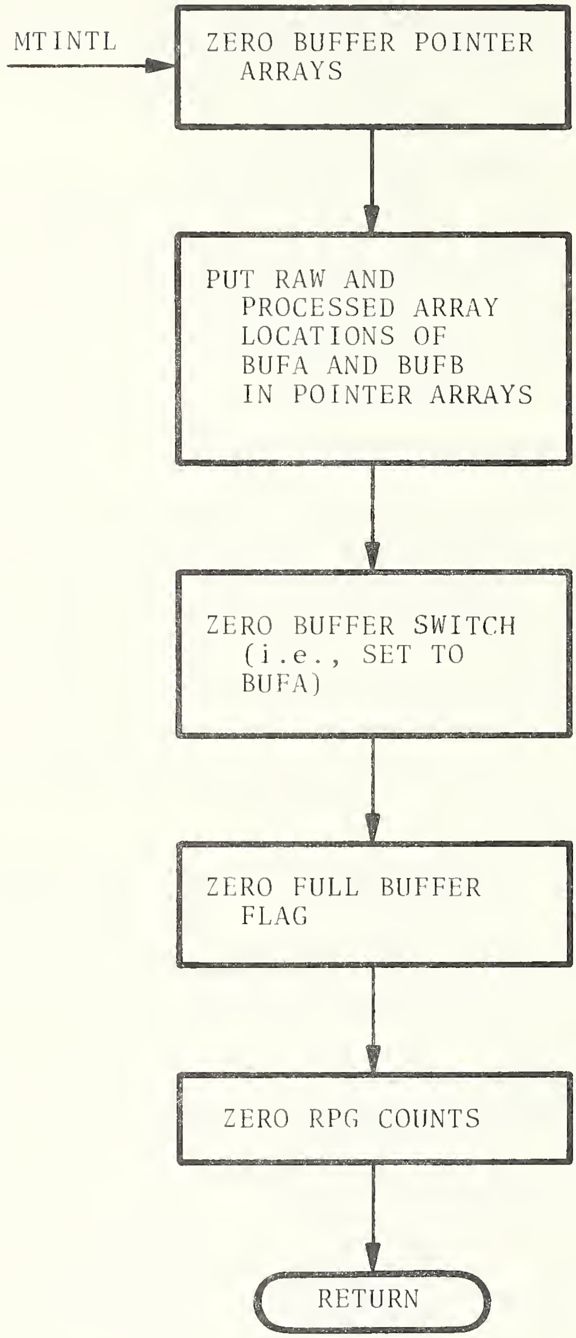


FIGURE 4-4. S1 MAGNETIC TAPE INITIALIZATION OUTPUT ROUTINE MTINTL

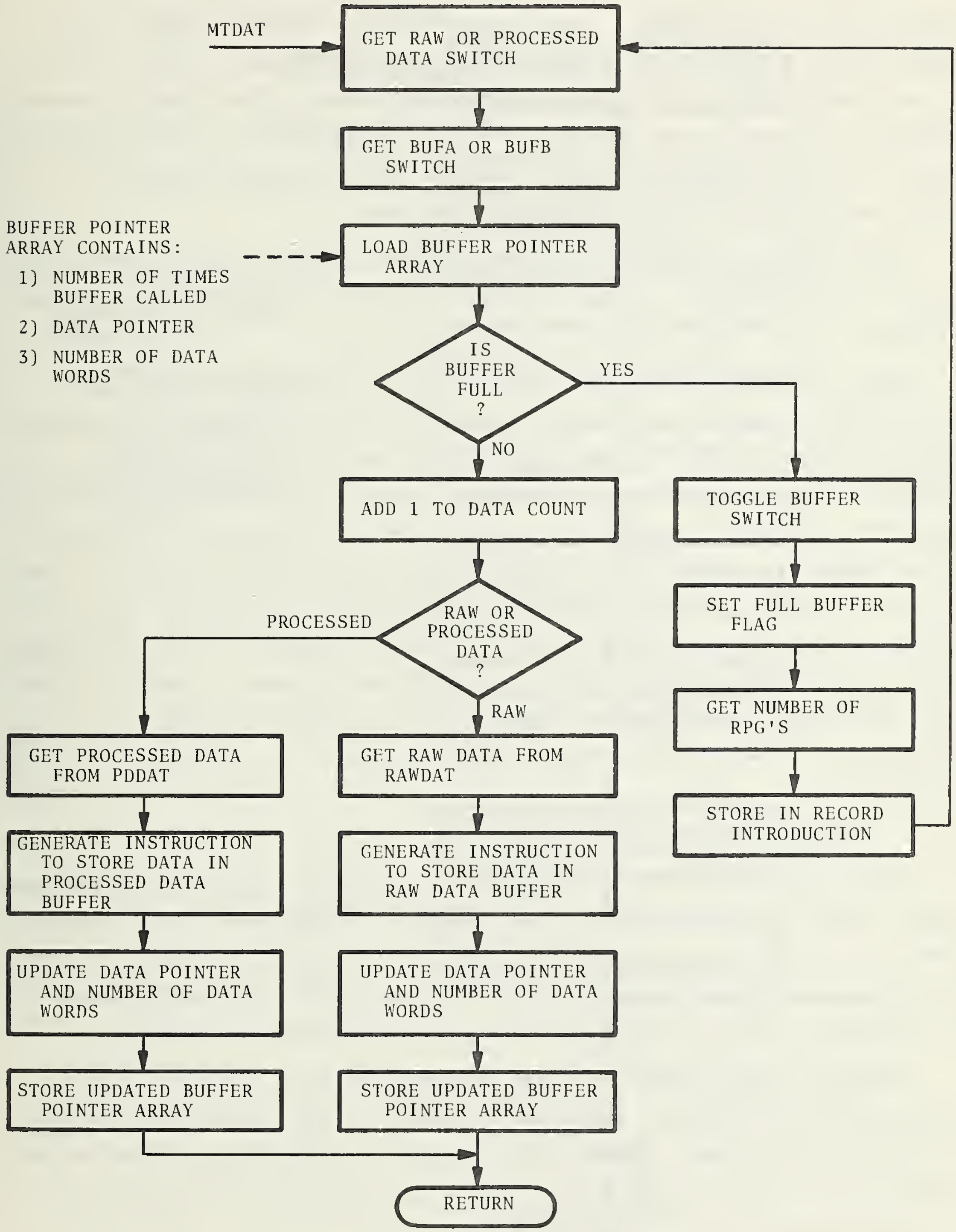


FIGURE 4-5. S1 MAGNETIC TAPE DATA STORAGE OUTPUT ROUTINE MTDAT

When the full buffer flag is set TGM6C outputs the full buffer by calling MTOUT. (See Figure 4-6.) MTOUT clears the buffer flag, then sets up the buffer control words. (See Figure 4-4 of the UNIVAC 1616 Technical Description.) The record introduction is stored into the buffer to be outputted. The pointer arrays are reinitialized and a flag is set to notify TGM6C to start generating a new record introduction.

The number of output records in incremented and magnetic tape output is initiated. As soon as the IOC is finished the routine returns.

Data is written out on the Brush Recorder by calling subroutine BR. (See Figure 4-7.) A data word is loaded in from the BRDATA array and bit 7, the sign bit of the byte in bits 0-7, is reversed. (See Appendix G, D/A Data Word.) The data word with the sign bit reversed is then stored back into the BRDATA array for use by TGM6C in generating the processed data output array. (See Section 2.4.3.) The byte in the right half of the data word is stored in the left half of a word in OUTBUF array. The right half will already contain the D/A subchannel designator. When all data words have been transferred, output on the Brush Recorder is initiated.

4.2.2 S2 Description

The routines in S2 allow data to be input in from a data tape rather than from the A/D's. The routine TGMMOD modifies codes in TGM6C prior to data processing. The routine INMCYC reads in the data tape and stores the raw data for the current minor cycle into the raw data input array, RAWDAT, for processing by TGM6C.

TGMMOD (Figure 4-8) sets up assigned memory addresses for processing interrupts. A header record is read into tape buffer BUFB for copying onto the output tape. The remaining three header records are skipped. This positions the tape at the beginning of first data record.

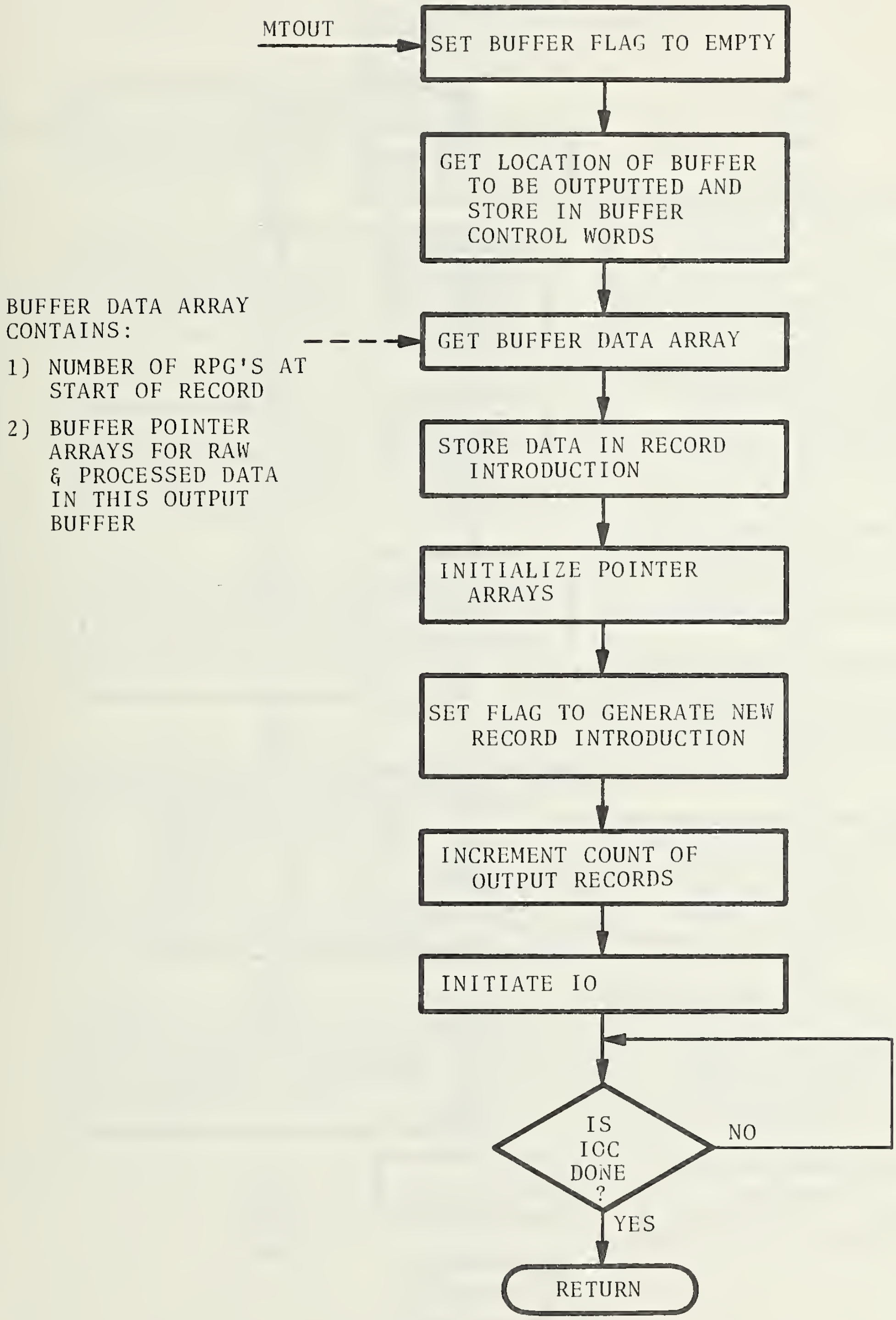


FIGURE 4-6. S1 MAGNETIC TAPE OUTPUT ROUTINE MTOUT

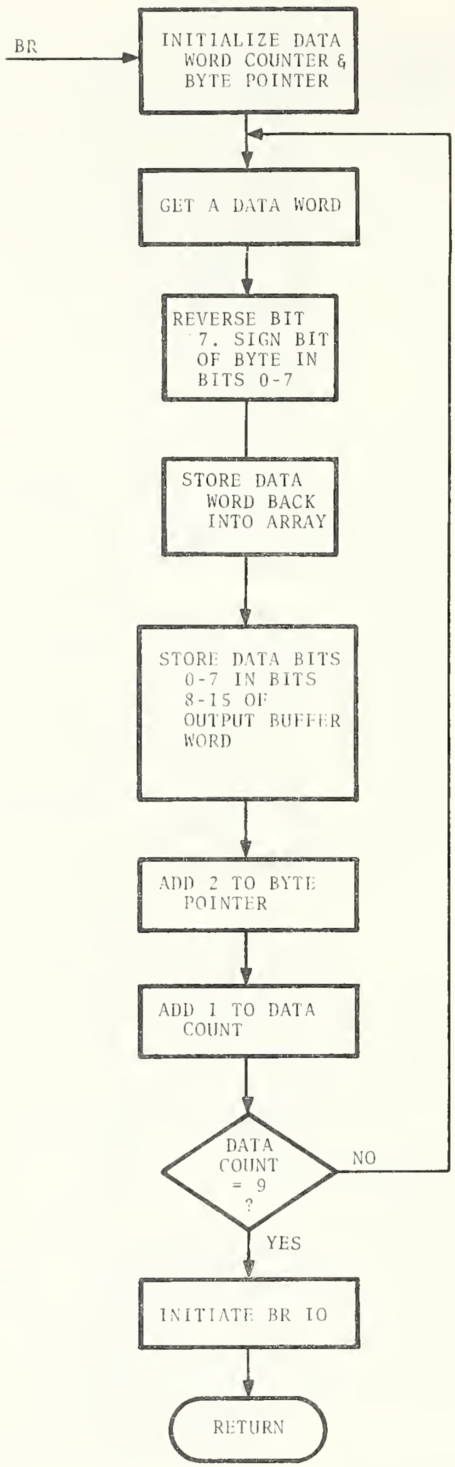


FIGURE 4-7. S1 BRUSH RECORDER OUTPUT ROUTINE BR

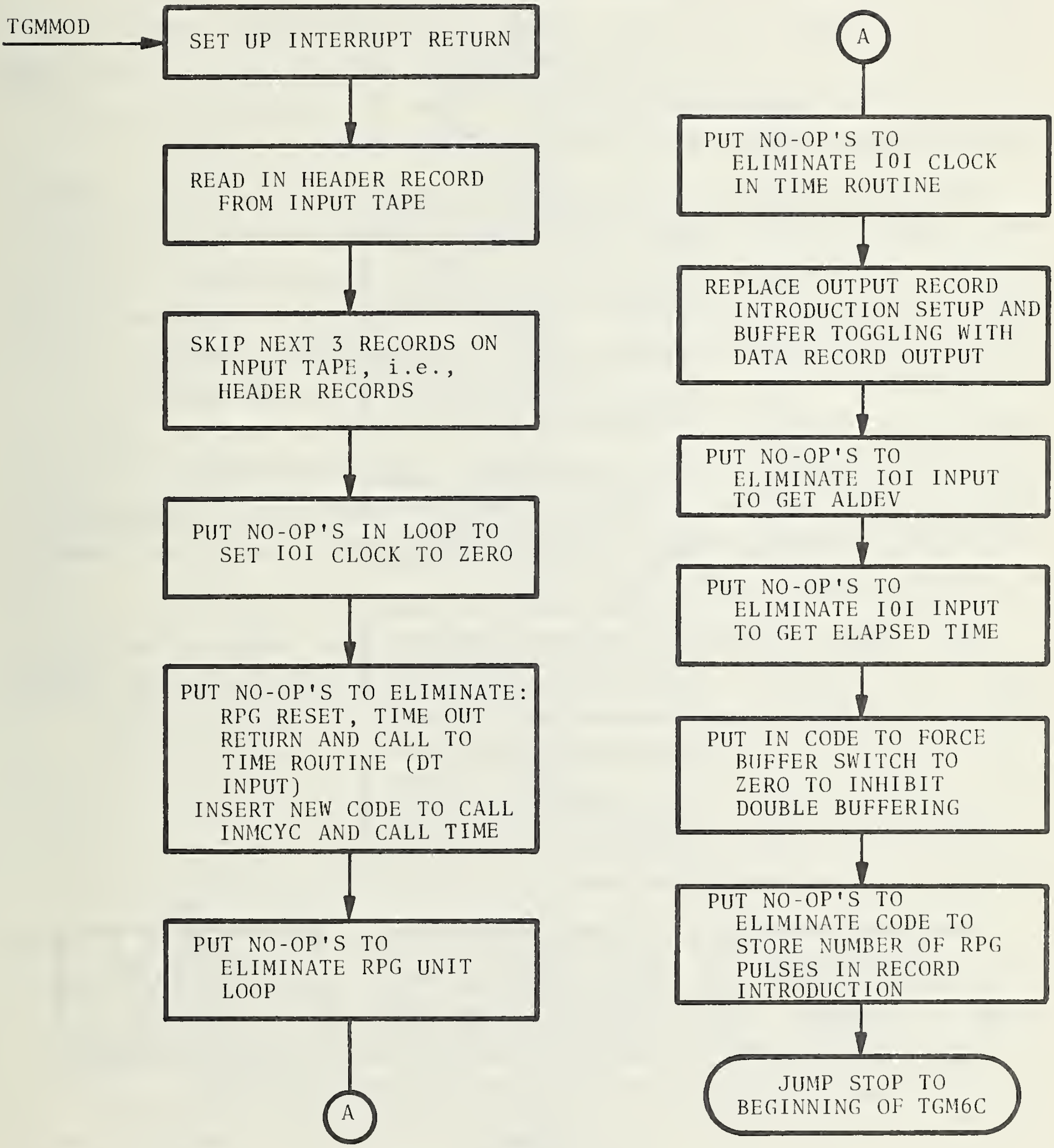


FIGURE 4-8. S2 ROUTINE TGMMOD

Some tasks that are necessary when processing in real time are not needed or must be modified. These tasks are eliminated by being overwritten by no-op's, i.e., an instruction that does nothing, or modified by overwriting the old code with new code. The loop to read in the first valid DT is eliminated. No-ops are read over the RPG reset, time out return, and DT input. New coding is inserted to call INMCYC for data input from mangetic tape and to call routine TIME to calculate TAU and TAU1I.

The RPG wait loop is eliminated. The coding in routine TIME for reading the IOI clock is eliminated. The record introduction is setup and the buffer switch toggle is replaced with a call to MTOUT to write out the output record. The magnetic tape interrupt return is eliminated in TGM6C since it has already been set up in S2. The call to the IOI for elapsed time and to get ALDEV are eliminated. Coding is altered to keep the buffer switch equal to zero which eliminates buffer switching. The code to store the number of RPG interrupts in the record introduction is eliminated. The program then jump stops to the TGM6C routine and is initiated by pressing start. (See Figure 4-1.)

The INMCYC routine (Figure 4-9) checks the number of words left in the buffer. If all words have been exhausted, a new record is read into BUFB, the minor cycle indicator is initialized to zero, the number of words in the buffer is set to 2300 and the data pointer initialized to BUFB+10.

The program then branches to that part of the program specified by the minor cycle indicator.

The only difference between minor cycles is the number of data words to be transferred. The number of data words is loaded and stored in RAWDAT. The data pointer and data word is loaded in, the data pointer incremented, and the data word stored in RAWDAT. A check is made to see if all data words have been transferred. If not, a new data word is retrieved and the process repeated until all data for this minor cycle has been transferred. The data pointer and remaining words in the buffer are stored. If this is

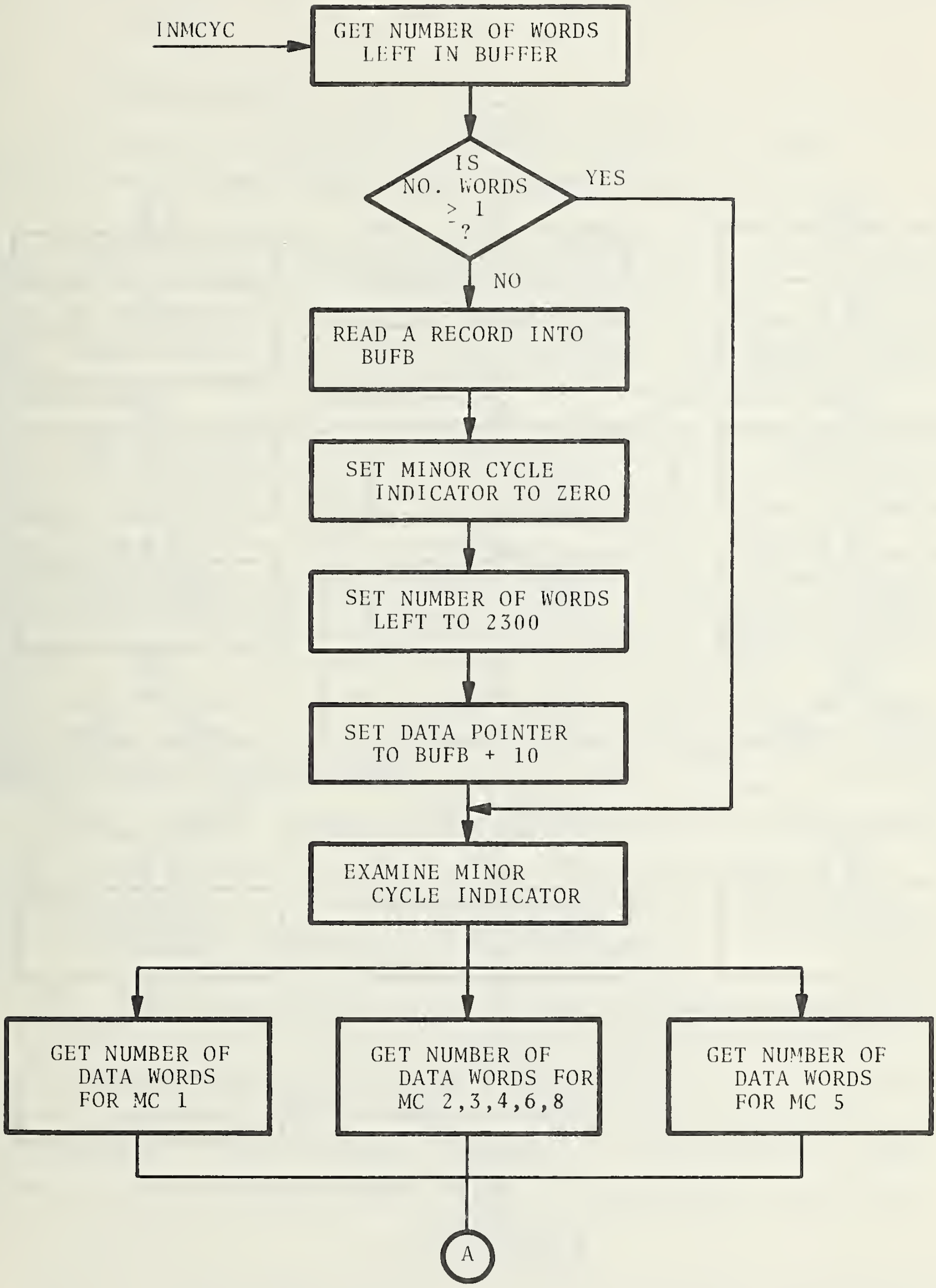


FIGURE 4-9. S2 ROUTINE INMCYC (SH. 1 of 2)

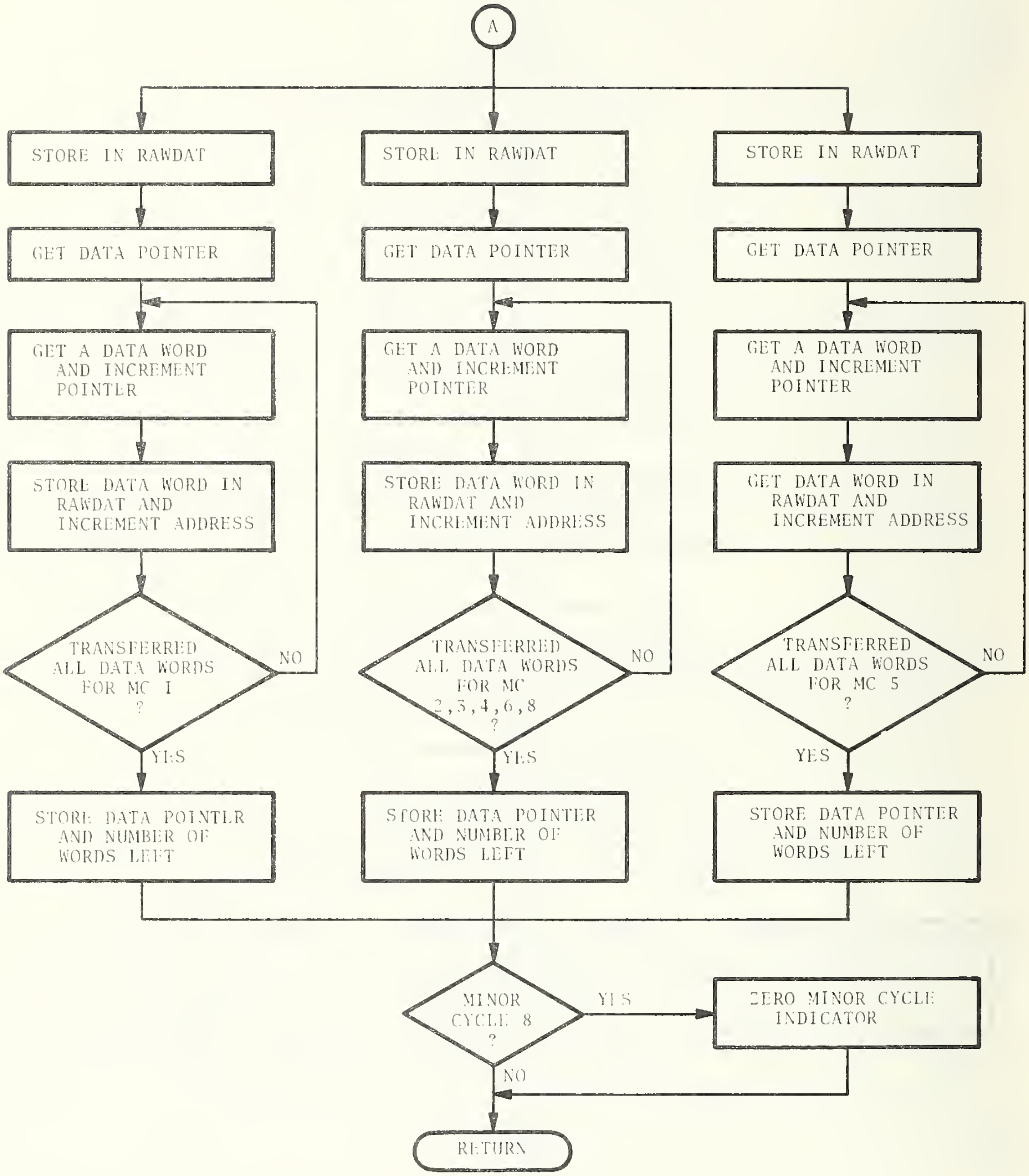


FIGURE 4-9. S2 ROUTINE INMCYC (SH. 2 of 2)

minor cycle 8 the minor cycle indicator is set to zero before the program returns.

4.2.3 S3 Description

The routine AVOLOR (Figure 4-10) averages the values of OL and OR from the last eight minor cycles.

The loops to process OL and OR are identical. A counter is initialized to seven and the sum initialized to zero. A value of OL or OR is loaded in from the raw data input array. It is shifted right three places, which is a division by 8, and added to the sum. The counter is checked for zero. If it is non-zero it is decremented and the program goes through the loop again. If it is zero the summing is complete, and the result is the average value of the last eight minor cycles. The average value is multiplied by a scale factor OLSF or ORSF to compensate for the variance of the actual gage sensor scaling from the ideal of ±5V corresponding to ±1-1/4 inches. These program scale factors are input by HEADER and are stored in the header record for use by TGM6C. The scale factor LSB requires a right shift by eight to restore the scale of OL or OR. The output, i.e., the averaged and scaled values of OL and OR are stored in ACP and ACP+1.

Routine RECOUT (Figure 4-11) calculates and scales the outputs to the chart recorder (Section 1.1). The first entry to the routine calculates a constant to be added to OL and OR to give gage. This constant centers gage at 57 inches.

The routine tests MCD, the midchord indicator. (See Appendix H.) If MCD is equal to 2, it will calculate midchord profile values (Section 1.1.1) and replace the alignments in the Brush Recorder output and in the magnetic tape processed data with midchord output. If the midchord indicator is not equal to 2 the alignments are calculated and output to the magnetic tape and chart recorders.

Gage is calculated from OL, OR and the constant CONST which was calculated upon ititial entry to RECOUT. It is scaled and stored for Brush Recorder and magnetic tape output.

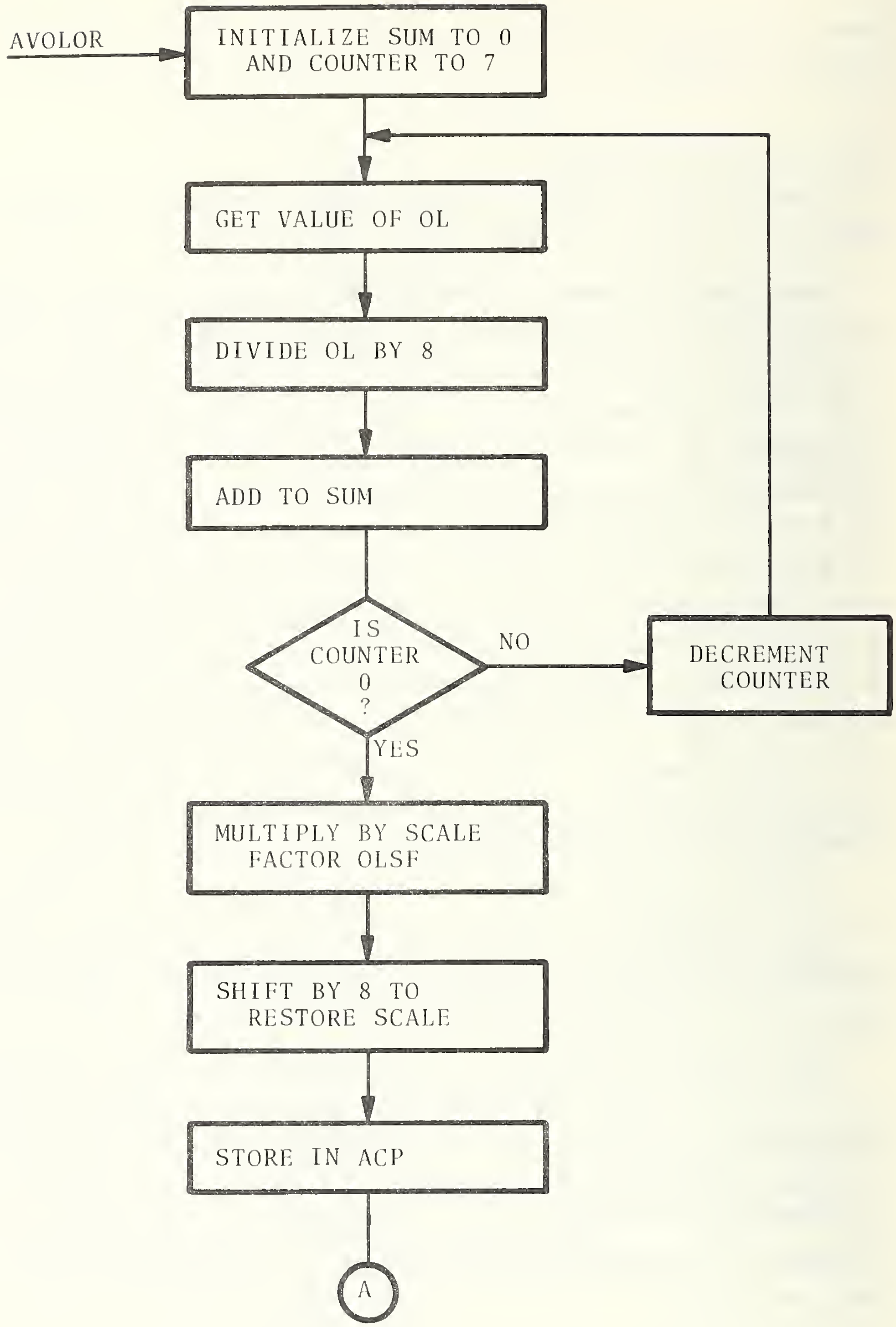


FIGURE 4-10. S3 ROUTINE AVOLOR (SH. 1 of 2)

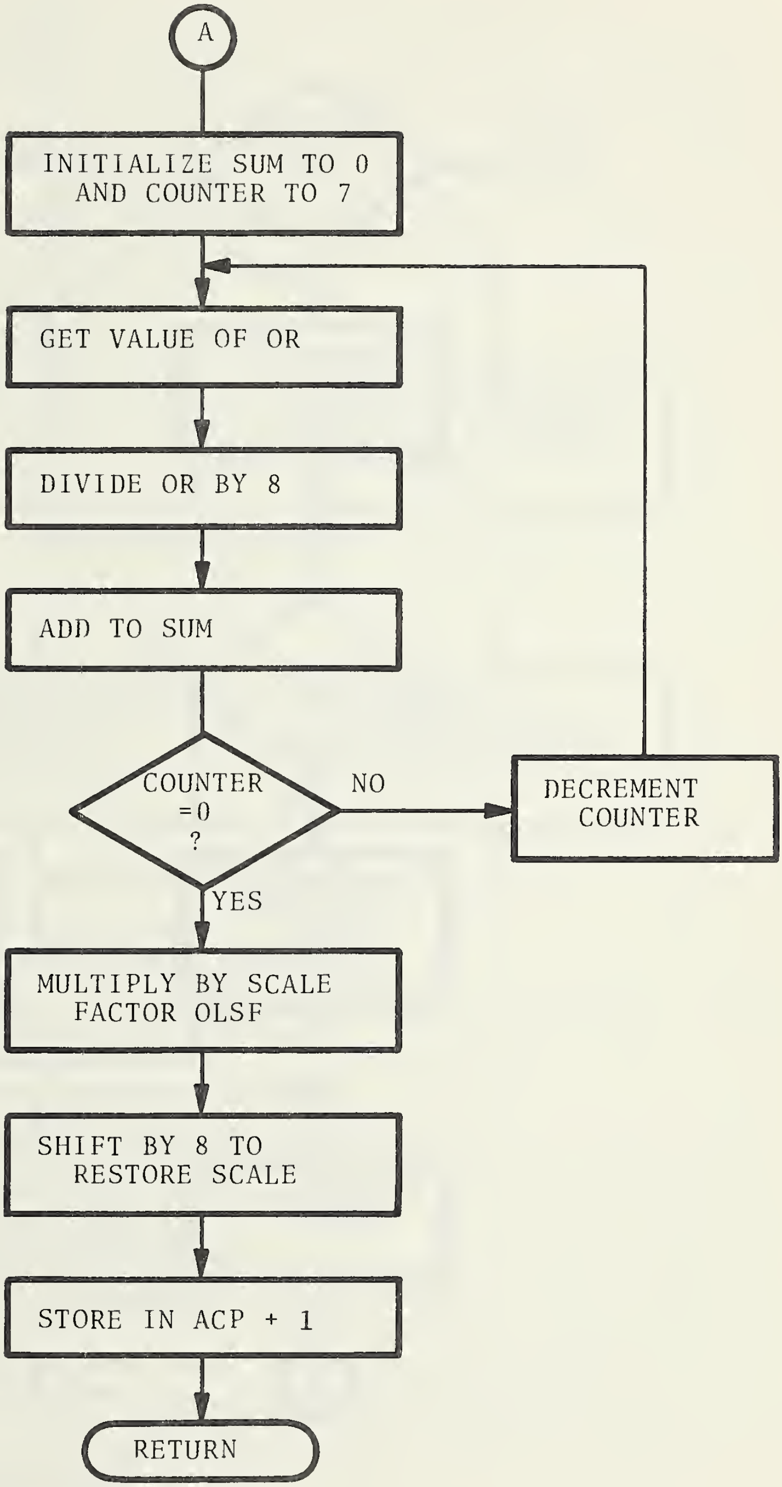


FIGURE 4-10. S3 ROUTINE AVOLOR (SH. 2 of 2)

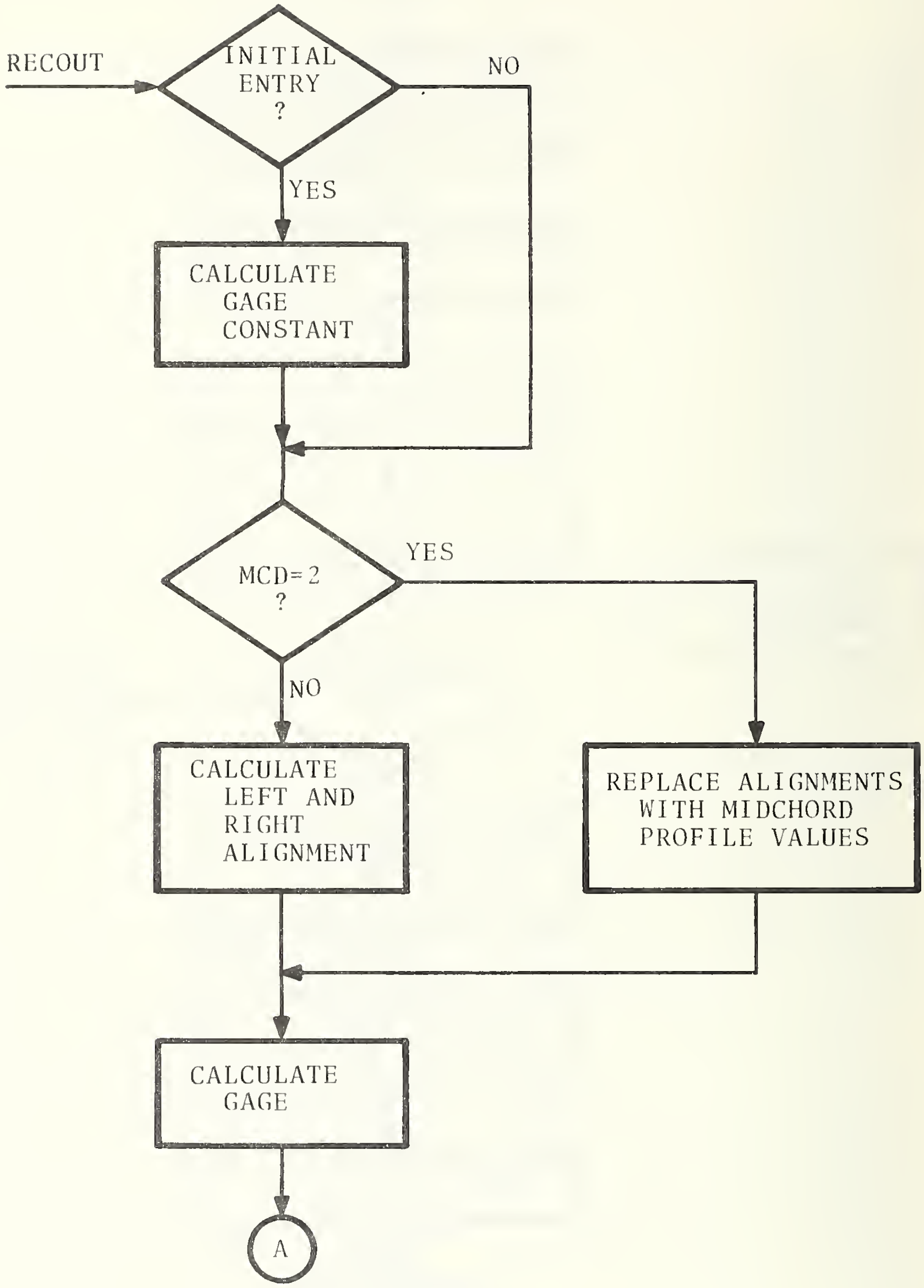


FIGURE 4-11. S3 ROUTINE RECOUT (SH. 1 of 2)

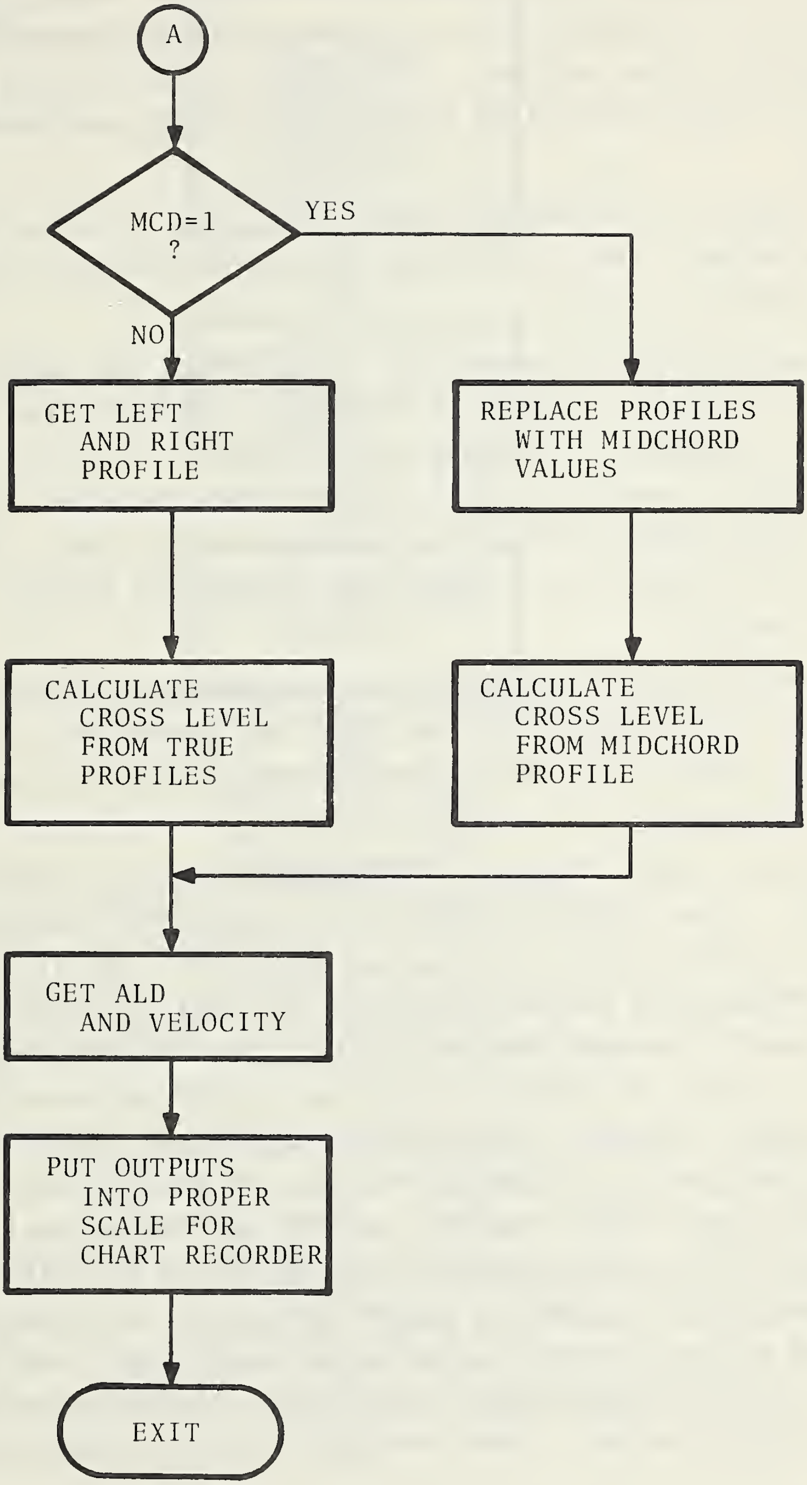


FIGURE 4-11. S3 ROUTINE RECOUT (SH. 2 of 2)

The routine again tests MCD. If MCD is equal to 1, true profiles are replaced with midchord profiles in the Brush Recorder and magnetic tape output. Cross level is calculated from midchord profile values and scaled for Brush Recorder and magnetic tape output.

If MCD is not equal to one, true profile values are scaled and outputted. The cross level is calculated from true profile and scaled for output.

The ALD bit is tested, if it is 1 then the output is set to 0100 so that when routine BR reverses sign bit 7 the voltage designator (Appendix G) will be +1.25 volts. If the ALD bit is zero the output is set to 0177700 so that when the sign bit 7 is reversed the voltage designator will be -1.25 volts. Next, the velocity is loaded in, scaled, and stored for output. The routine then returns.

Routine DAINIT (Figure 4-12) zeroes out all variables in DBRO. It zeroes the VSSAVE array in TGM6C and zeroes TPL, TPR, PL, PR, and I in routine AB. Variables are initialized to zero prior to data collection.

Routine DBRO (Figure 4-13) aligns data for output to the chart recorder. (See Section 2.5.) The indices for loading data values into the delay arrays are located in R1, R2. R1 is the index for values delayed by 64 feet which is the current value of λ. R2 is the index for values delayed 32 feet. The delayed values are loaded in from the delay arrays, and stored in locations, OLD, ORD, ALDD, ALATD, and TAU1. The average of OL and OR for the last eight minor cycles is loaded in from ACP and ACP+1, and stored in the delay arrays OLT, and ORT. ALATR and TAU1I, the sum of the last eight DT's, are loaded in and stored in the delay arrays ALATT and TAU1T. ALDEV is loaded in and bit 15, the ALD bit, is stripped off and stored in the delay array ALDD. The delay array indices are incremented and set back to zero if they are equal to their maximum values. They are then stored in INDX.

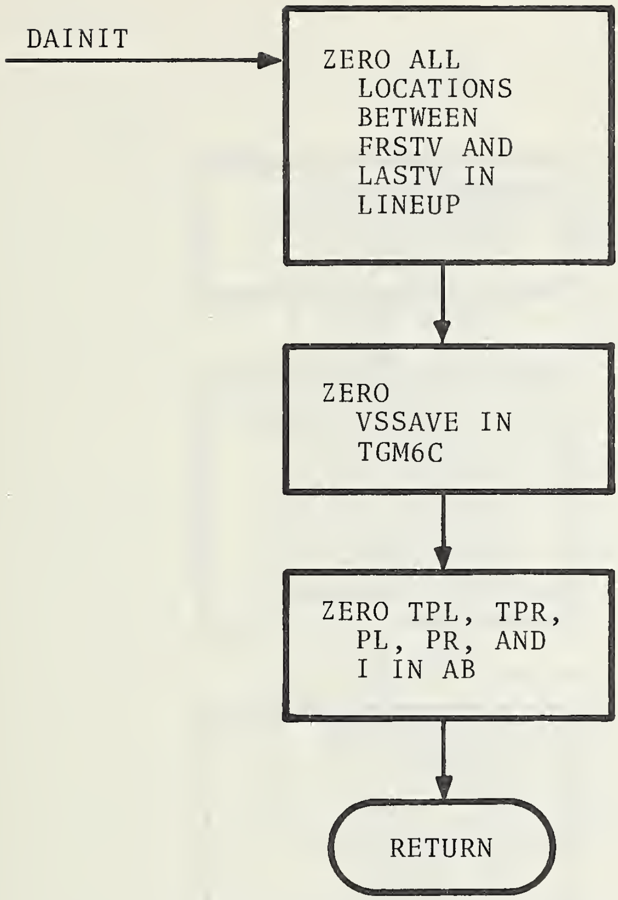
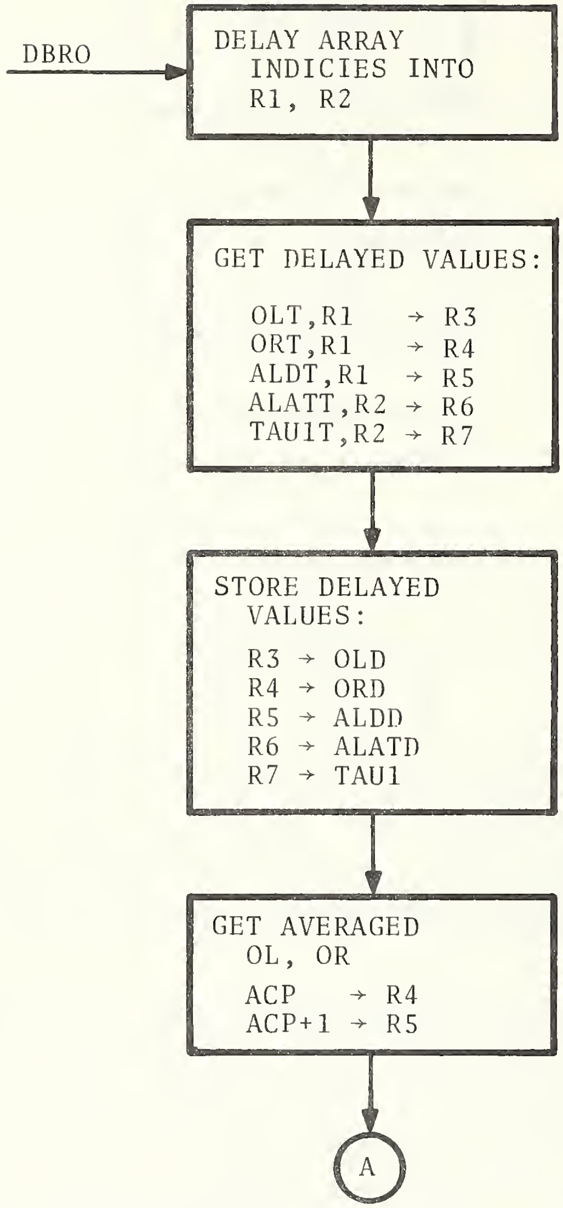


FIGURE 4-12. S3 ROUTINE DAINIT

ABIN (Figure 4-14) puts PL and PR into delay arrays (Section 2.5), and gravity corrects the lateral accelerometer. (See Appendix E.)

DPL and DPR, the double precision profile outputs from DINT1 and DINT2, are loaded into R3 and R4, respectively. The delay array index I is stored in R1. If R1 is less than 64 the program continues otherwise R1 is set to zero before continuing. Delayed values of profile left and profile right are loaded in from the delay arrays R5 and R6 and stored in PR and PL. R3 and R4 are then stored into the delay arrays. The array index in R1 is incremented and stored.

The ALATR is then gravity corrected by subtracting R4 from R3 to get cross level XL. XL is multiplied by GGR which is a



NOTE: ALIGN OUTPUT TO BRUSH RECORDER (SEE FIGURE 2-2)

FIGURE 4-13. S3 ROUTINE DBRO (SH. 1 of 3)

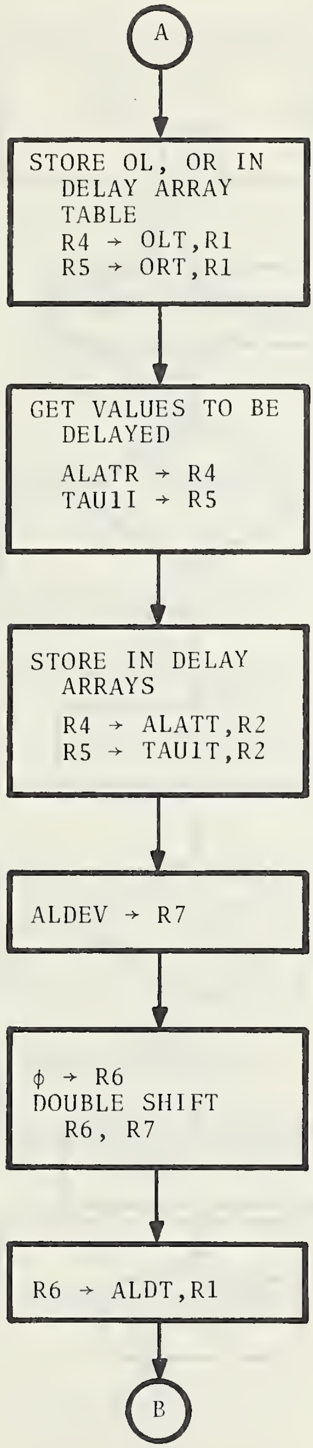


FIGURE 4-13. S3 ROUTINE DBRO (SH. 2 of 3)

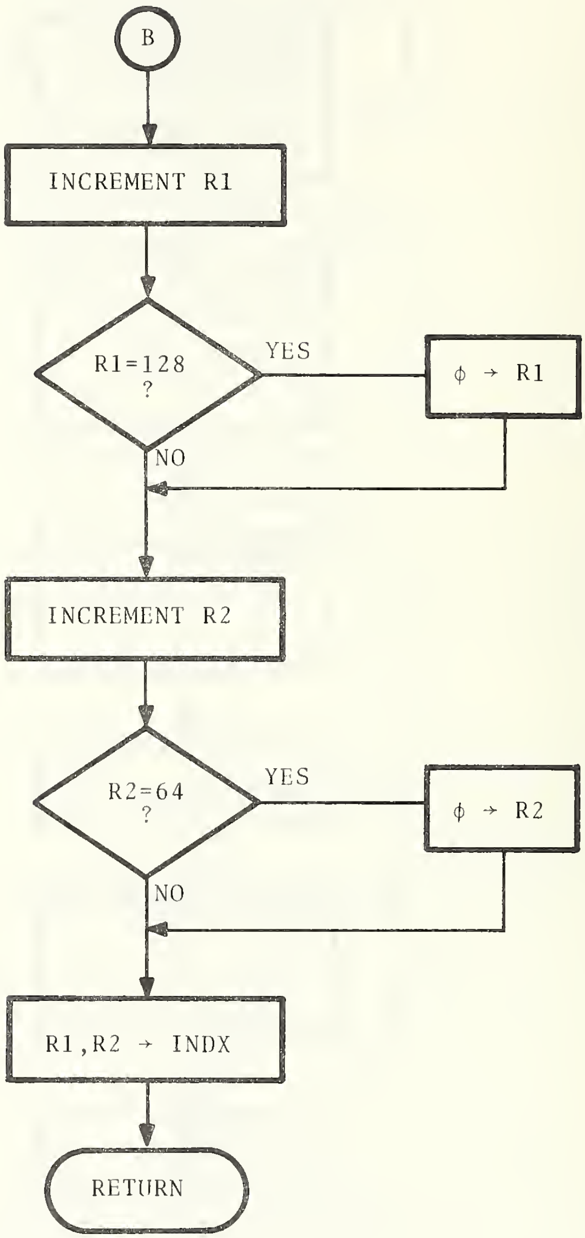


FIGURE 4-13. S3 ROUTINE DBRO (SH. 3 of 3)

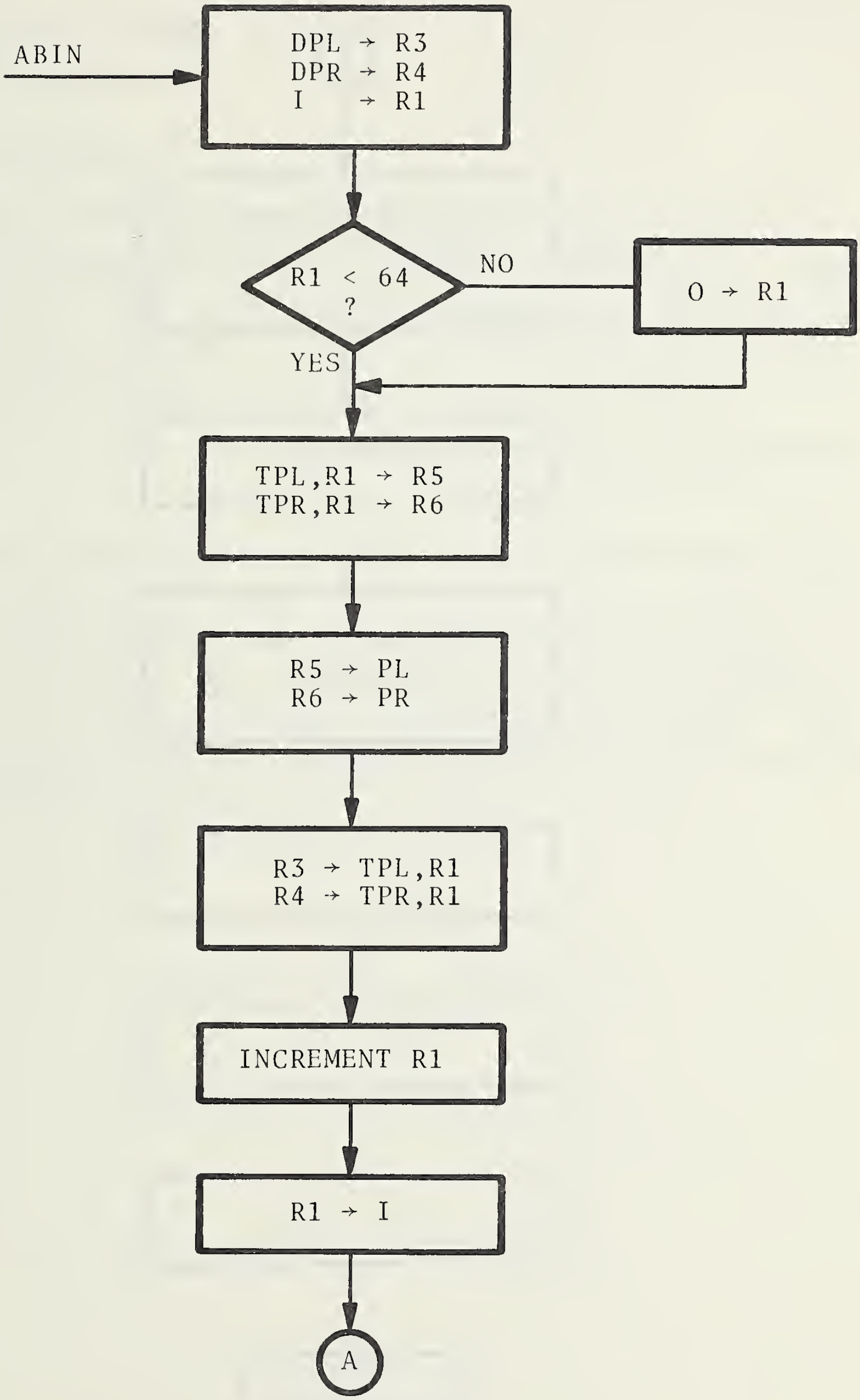


FIGURE 4-14. S3 ROUTINE ABIN (SH. 1 of 2)

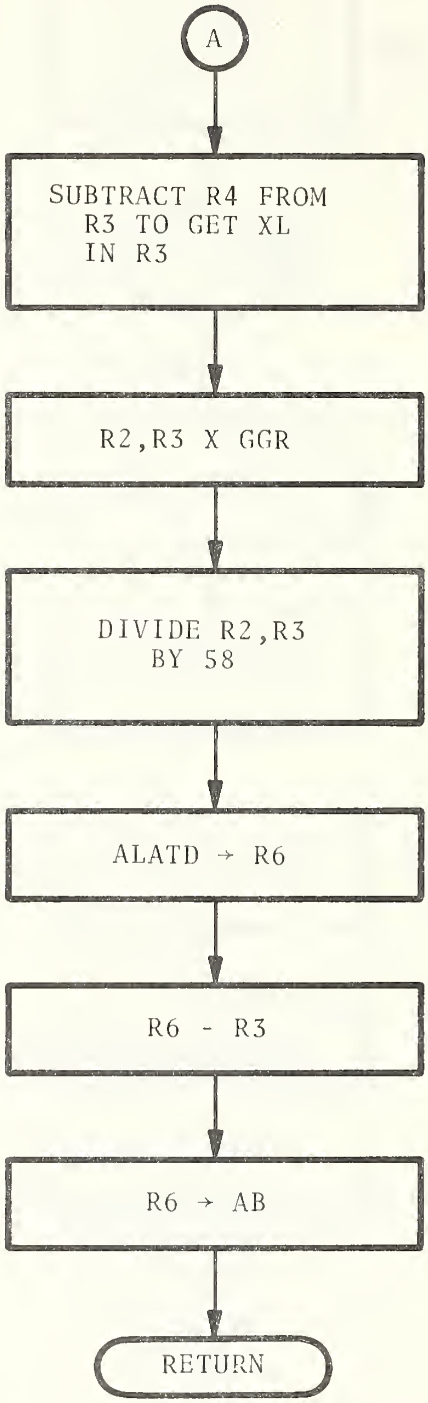


FIGURE 4-14. S3 ROUTINE ABIN (SH. 2 of 2)

constant in the header parameter array. The double precision result in R2, R3 is divided by 58 to scale the result and put it into R3. ALATD is loaded in R6 and R3 is subtracted from R6 and the result stored in AB.

4.2.4 S4 Description

The double integration routines are straightforward and follow the algorithm devised by P. Mengert (Appendix B). Since the algorithm must run in real-time, the code has been tightened wherever possible. Numbers are shifted when necessary to prevent underflow and overflow.

The ability to produce 62-foot midchord data is available as an option.

The double integration of AJL and AJR is done exactly the same. The integration of ALAT is different only in that ALAT is sampled once every major cycle while AJL and AJR are sampled twice. This is reflected in the smoothing algorithm where AJL and AJR are averaged over a major cycle before smoothing. The flow chart (Figure 4-15) is for the double integration of AJL but applies equally to AJR and ALAT.

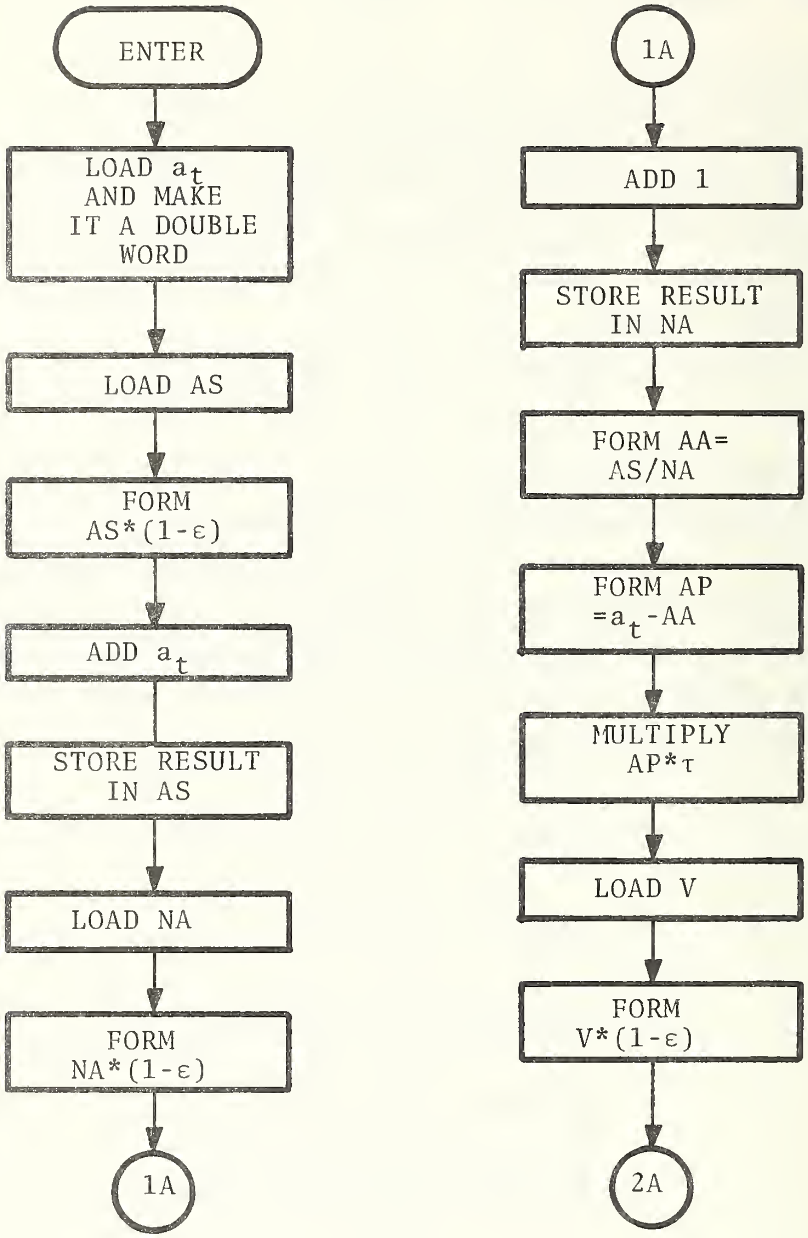


FIGURE 4-15. S4 DOUBLE INTEGRATION ROUTINE (SH. 1 of 4)

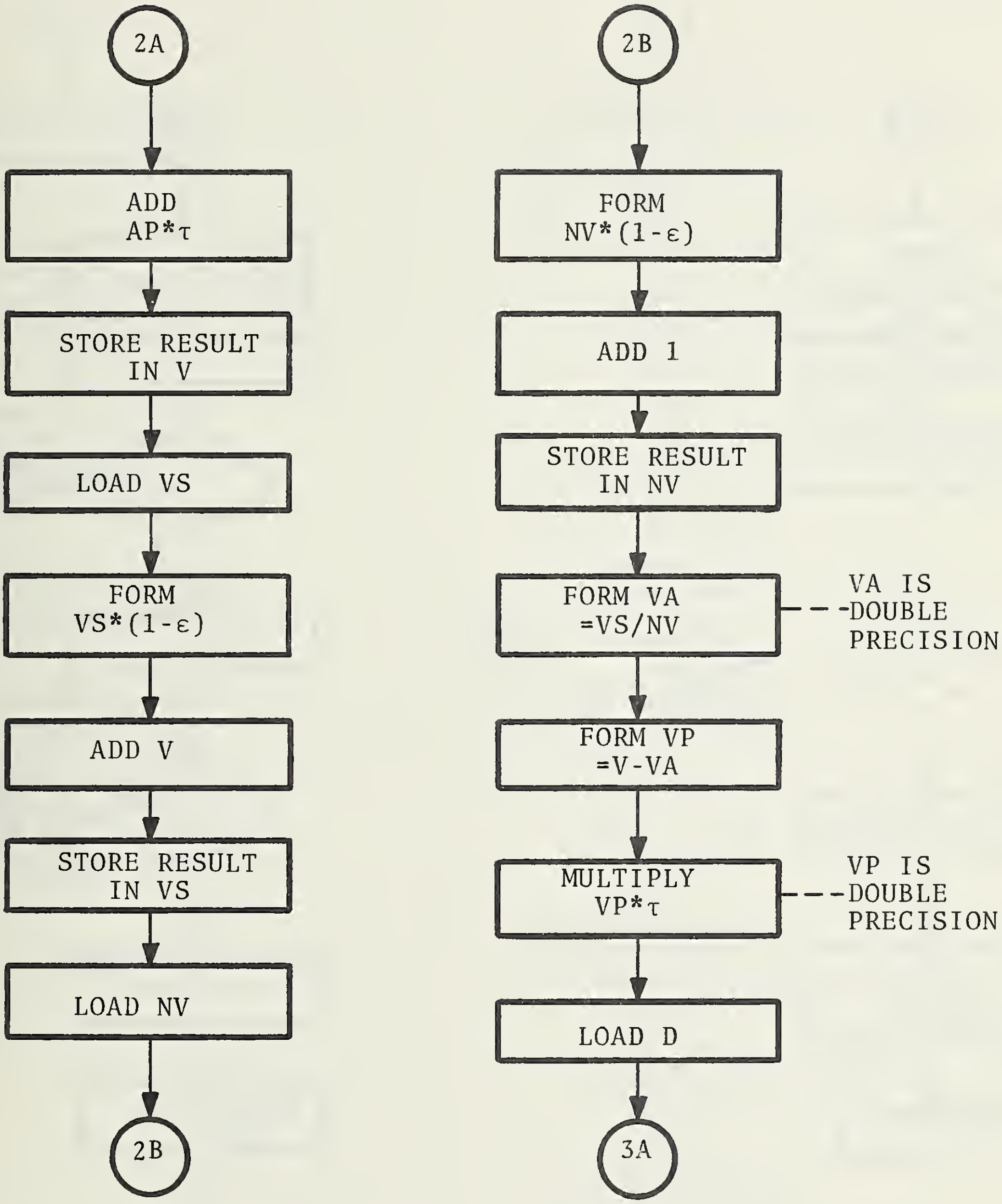


FIGURE 4-15. S4 DOUBLE INTEGRATION ROUTINE (SH. 2 of 4)

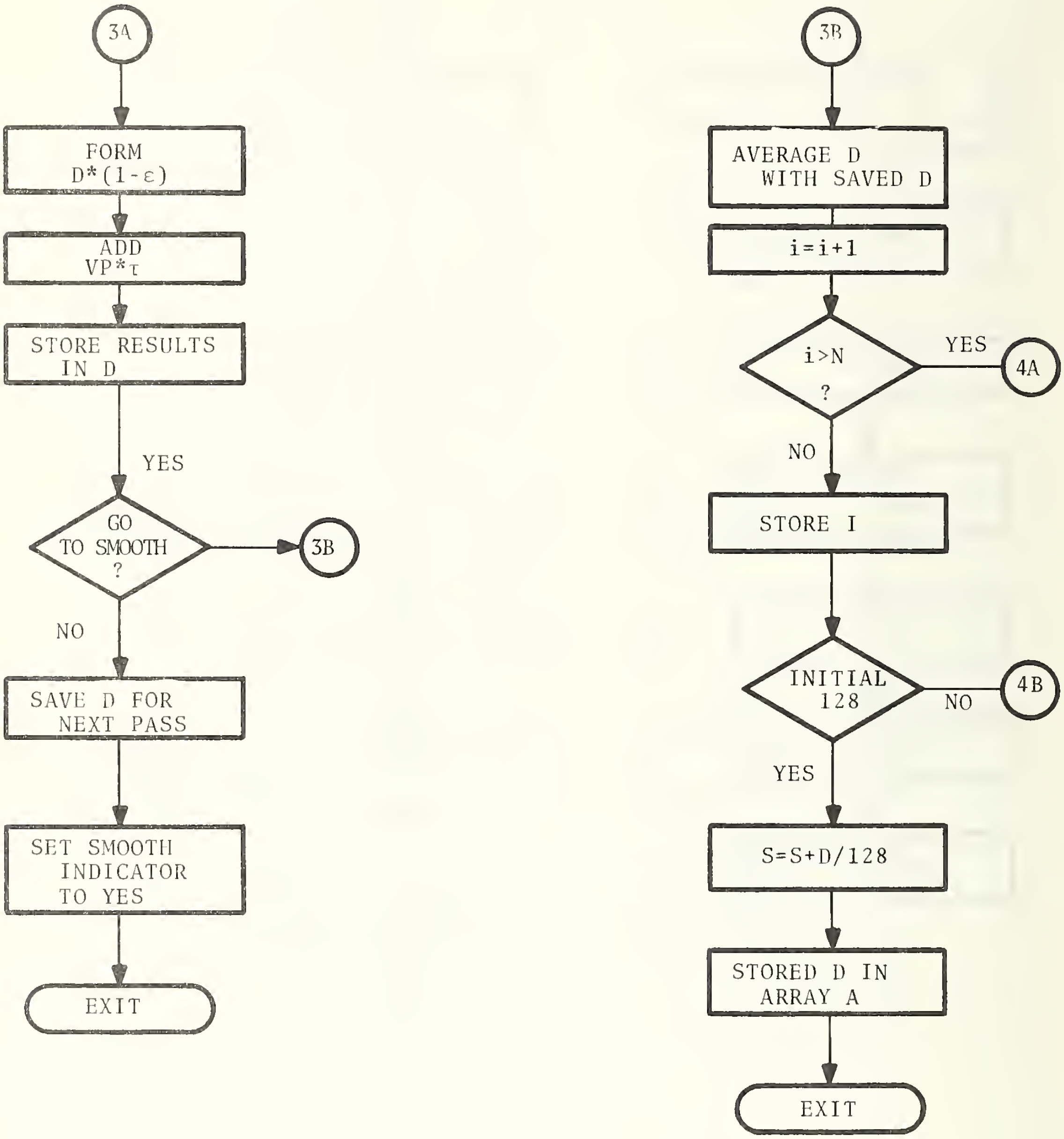


FIGURE 4-15. S4 DOUBLE INTEGRATION ROUTINE (SH. 3 of 4)

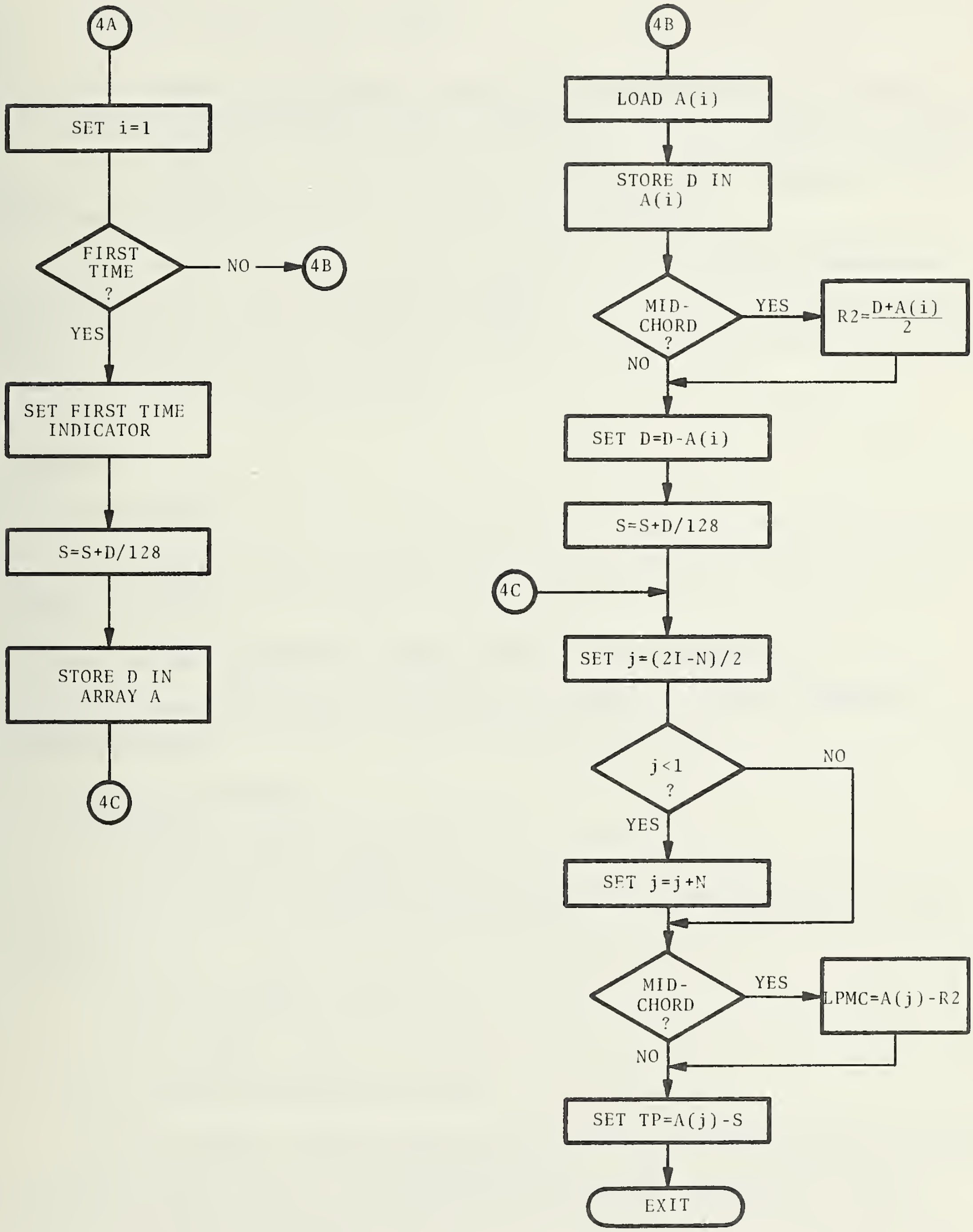


FIGURE 4-15. S4 DOUBLE INTEGRATION ROUTINE (SH. 4 of 4)

5. TGM6C PROGRAM OPERATING INSTRUCTIONS

5.1 SYSTEM VALIDATION PROGRAM

The system validation program is a selfcontained program in an off-line mode designed to exercise vehicle support hardware.

The program is controlled by teletype input commands with teletype error messages for incorrect commands.

The system validates the program. It is not a diagnostic program and will not pinpoint errors. It will not test multiple device interactions or detect errors in one device which are being caused by device interaction.

EXECUTION

A. Test Setup

1. Check system validation tape to ensure read/write ring is not present

2. Load validation tape on T1. (See Appendix I.)

3. Place teletype in ON-LINE position and the FUNCTION switch to KT.

B. Loading Procedure

1. On CPU front panel

a. Press top MASTER CLEAR and the two REGISTER CLEAR switches.

b. Set MODE = RUN

c. Set P = 10

2. Press START/STEP on CPU

At this point, the program will load into memory and the CPU will halt at P = 51. If the system does not load correctly, clear controller, rewind and repeat the procedure beginning at Step B.1. (Also see Step D.)

C. Executing Test

1. With CPU at P = 51, press MASTER CLEAR switch, set MODE = RUN and P = 10000.

2. Press START/STEP on CPU

If the teletype responds by printing SELECT TEST, proceed with Step E. If the teletype fails to respond, try the error recovery procedures in Step D.

D. Error Recovery

1. Check hardware and repeat loading procedure starting at Step A.2.

2. Execute loading procedures using system validation back-up program tape.

3. Mount validation tape on T1 and clear controller. Repeat loading procedures beginning at Step B.1.

E. Control Codes

The objective of the system validation program is to assure proper function of the subsystems in the data acquisition system (DAS-1). All subsystems except the UNIVAC 1616 Computer and the three 8K memory banks are tested.

Once the system validation program is loaded and execution has been initiated, the message SELECT TEST is printed on the teletype (TTY) printer. The operator responds by typing on the TTY keyboard one of the following selection codes in parentheses followed by pressing CTRL and EOT at the same time on the teletype keyboard.

- Teletype Keyboard (TK)
- Paper Tape (PT)
- Line Printer (LP)
- Magnetic Tape (MT)
- Analog-to-Digital Conversion (AD)

— Digital-to-Analog Conversion (DA)

If an error is made in the test selection, the message TRY AGAIN is printed on the TTY printer and the test selection is repeated.

1. Teletype Keyboard Test (TK)

a. Upon entry to this test, the message will be printed on the TTY printer.

b. The operator types a character string ending with an even number, if less than 200 characters, followed by an EOT or he types a character string of exactly 200 characters (but not followed by an EOT).

c. The program responds by printing on the TTY printer the character string just input.

d. Steps 1.b and 1.c should be repeated four additional times. After the last (fifth) character string has been input and the image character string has been printed, program operation will be returned to the monitor program.

e. The monitor program will issue the message SELECT TEST on the TTY printer. Now the operator may select another test.

2. Paper Tape Punch Test (PT)

a. Upon entry to this test, 56 frames of leader followed by 63 frames of characters will be punched on paper tape.

b. The combined 119-frame pattern will be repeated four more times. The program will then cause the reading of these five sets of 119 frames and verify that the proper information was punched on the tape. The SWITCH ON reader must be set to the RUN position.

c. If an error is encountered during the verify operation, the message PTER will be printed on the TTY and program execution will stop.

d. To resume execution, momentarily depress the START/ STEP switch.

e. Upon completion of the Paper Tape Punch test, control will be returned to the monitor program.

f. The monitor program will issue the message SELECT TEST on the TTY printer. Now the operator may select another test.

3. Line Printer Test (LP)

a. Upon entry to this test, the message LPV, will be printed on the TTY printer.

b. The program will print 128 character-strings of 132 characters on the line printer. Each string is a cyclical permutation of the previous string.

c. Then, four additional lines will be printed on the line printer.

The character strings are as follows:

1. A sixty-character string followed by EOT
2. A fifty-character string followed by LF
3. A forty-character string followed by FF
4. A thirty-character string followed by CR.

d. Upon completion of the Line Printer test, control will be returned to the monitor program.

e. The monitor program will issue the message SELECT TEST on the TTY printer. Now the operator may select another test.

4. Magnetic Tape Test (MT)

a. Upon entering this test, various commands will be issued to T1 and proper response will be tested. If an error is encountered, an error message MTER XXXXXX, GOOD YYYYYYYYYYYYYYYY and BAD ZZZZZZZZZZZZZZZZ will be printed on the TTY printer - GOOD indicates the intended data pattern and BAD indicates the actual data pattern (See Table 5-1.)

TABLE 5-1. MAGNETIC TAPE ERROR CODES

MTER XX XXXX

XX	XXXX		
	PER-	PARITY ERROR	STATUS CODES
	RJT-	REJECT	
	CBY-	CONTROLLER BUSY	
	FPT-	FILE PROTECT	
	NRDY-	NOT READY	
	OLR-	ODD LENGTH ERROR	
	EOT-	END ON TAPE	
	BOT-	BEGINNING ON TAPE	
RE -		RESET	COMMAND CODES
SL-		SELECT TAPE UNIT	
FM-		FILE MARK	
WG-		WRITE 3" GAP	
FS-		FORWARD SPACE ONE RECORD	
RD-		READ ONE RECORD	
RW-		REWIND	
WT-		WRITE ONE RECORD	
RS-		REVERSE SPACE ONE RECORD	

b. When the Magnetic Tape test is completed, control is returned to the monitor program.

c. The monitor program will issue the message SELECT TEST on the TTY printer.

d. Now the operator can repeat the tests for other tape units.

5. Analog-to-Digital Conversion Test (AD)

a. Upon entering this test, the message MODE will be printed on the TTY printer.

b. The operator may type any one of the following codes. (Note: There is no space between the period and (CTRL-EOT).)

1 .(CTRL-EOT)

For sequential mode input from all subchannels (00 through 31).

2 .(CTRL-EOT)

For random mode input from all subchannels.

3 .(CTRL-EOT)

XX for single subchannel mode, XX = subchannel number from (00 to 31).

4 .(CTRL-EOT)

For packed sequential mode.

c. The data output resulting from executing the A/D conversion test under one of the above four options will be printed on the VERSATEC line printer.

d. To terminate this test, the operator types a T code followed by an EOT on the TTY. This action causes program control to be transferred to the monitor.

e. The monitor program will issue the message SELECT TEST on the TTY printer. Now the operator may select another test.

6. Digital-to-Analog Conversion Test (DA)

a. Upon entering this test, a sawtooth pattern will be output to the brush recorder. The displacement values issued for the sawtooth pattern will vary from 0 to 0377.

b. The sawtooth pattern will be generated continuously until the operator enters a T code on the TTY followed by an EOT or the operator inputs a new output voltage value in binary notation. Admissible voltage values are 0 to 11111111_2. This will give rise to a fixed output level. Additional voltage values may be input if another fixed output level is desired. The operation may be terminated by a T code and an EOT command.

c. Program operation will be returned to the monitor and the message SELECT TEST will be issued on the TTY printer. Now the operator may select another test.

5.2 HEADER PROGRAM DATA TAPE

The HEADER program is used to create a header and parameter record whose information is used by the data collection system (TGM6C).

When the HEADER program is executed, it initiates a series of operating questions and stores the answers in core. Upon completion of the questions, the HDDMP program transfers the answers to a magnetic tape in a form useable by the measuring system. Any changes to the header information will require creation of a new header data tape.

The header information must be loaded into the CPU each time the TGM6C data collection system is loaded.

EXECUTION

A. Test Setup

1. Mount HEADER program tape on T1 (see Appendix I).

2. Put teletype in ON-LINE position and FUNCTION switch to KT.

3. Turn line printer POWER switch to ON.

B. Loading Procedure

1. Clear CPU using MASTER CLEAR and two REGISTER CLEAR switches:

2. Set MODE = RUN and P = 10.

3. Press START/STEP switch four times.

C. HEADER Program Execution

1. Clear CPU by pressing MASTER CLEAR and two REGISTER CLEAR switches.

2. Set P = 035700 and press START/STEP switch.

3. The system indicates it is operational by typing an @? on the TTY.

4. Type XC 503 ↓ to begin execution of the HEADER program.

The following is a list of the HEADER questions. Optional answers will be shown as "A's" for alphanumeric responses and "X's" for numeric responses. All required answers will be shown as constants. Also see the following example.

INPUT? (Y OR N) - "Y"

DATA YEAR - XX

MONTH - XX

DAY - XX

TYPE OF TEST - A's

TRAIN CONSIST - A's

TEST CONTROLLER - A's

MOTORMAN - A's

INSTRUMENTATION OPERATOR - A's

COMPUTER OPERATOR - A's

TEST PROJECT MANAGER - A's

REAR OBSERVER - A's

CHIEF TEST ENGINEER - A's

LOG KEEPER - A's

OPERATING PROPERTY - A's

ROUTE IDENTIFICATION - A's

TRAIN POSITION AT START OF TEST - A's

EXPECTED POSITION AT END OF TEST - X's

EQUIPMENT LIST - A's

RECORD FORMAT - "2300 WORDS"

RPG WHEEL CIRCUMFERENCE IN INCHES - "102.98562"

RPG PULSE DIVISOR - "7"

EXACT DISTANCE INCREMENT OF INTERRUPT INCHES - "0.7209"

BASE CLOCK USED TO COMPUTE DELTA T - "100 kHz"

GAGE BEAM LENGTH - 4 FEET PLUS (INCHES) - "9.6512"

AVL

CHANNEL - "9"

RATE SAMPLE/FOOT - "4"

WORD SIZE (H or F) - "F"

SCALE FACTOR - "1"

AVR

CHANNEL - "11"

RATE SAMPLE/FOOT - "4"

WORD SIZE (H OR F) - "F"

SCALE FACTOR - "1"

ALAT

CHANNEL - "13"

RATE SAMPLE/FOOT - "2"

WORD SIZE (H OR F) - "F"

SCALE FACTOR - "1"

<u>OL</u>

CHANNEL - "7"

RATE SAMPLE/FOOT -"16"

WORD SIZE (H OR F) - "F"

SCALE FACTOR - "0.9551"

<u>OR</u>

CHANNEL - "5"

RATE SAMPLE/FOOT - "16"

WORD SIZE (H OR F) - "F"

SCALE FACTOR - "0.9792"

<u>HAVL</u>

CHANNEL -"1"

RATE SAMPLE/FOOT - "16"

WORD SIZE (H OR F) - "F"

SCALE FACTOR - "1"

<u>HAVR</u>

CHANNEL - "3"

RATE SAMPLE/FOOT - "16"

WORD SIZE (H OR F) - "F"

SCALE FACTOR - "1"

SV INCH/SAMPLE OF AJL - "2.8836"

BG DISTANCE GAGE TO AJL - "19.5"

BGLAT DISTANCE GAGE TO ALAT - "0"

BDALD DISTANCE GAGE TO ALD - "5"

TV AJL TIME DELAY - "42.8"

TLAT ALAT TIME DELAY - "42.8"

TD ALD TIME DELAY "2"

GGR GRAVITY CORRECTION CONSTANT - "6.59895"

TG OL TIME DELAY - "5"

H UNCOUPLING CONSTANT - "0.17512"

COMMENTS - A's

PRINTOUT (Y OR N) answer according to desire for line printer output.

DONE

HEADER questions are now complete and the HEADER data tape should be mounted on T1.

D. Building Bootstrap Header Data Tape

There are two sections of data that should be put on the header bootstrap data tape. They are from 015701 to 021677 and from 030117 and 030277. To put these areas on tape in bootstrap format, program HDDMP is executed.

E. HDDMP Program Execution

1. Mount output tape on T2.

2. Clear CPU by pressing MASTER CLEAR and two REGISTER CLEAR switches.

3. Set P = 035700 and press START/STEP switch.

4. The system indicates it is operational by typing on @? on the TTY.

5. Type XC 12000 ↓ to execute HDDMP program.

Header data tape is now ready to be loaded for use by the data collection system.

F. Creating New Header Tape

It is also possible to make a new header data tape using an old header tape. To do this, mount the old bootstrap data tape and boot in both records. Boot in the HEADER program from the bootstrap program tape as previously defined. When the program types out:

INPUT? (Y OR N) - answer "N"

This puts the program into edit mode, and the program types

LINE NUMBER?

Answer with the line number that you wish to edit. For example, if you wish to edit the date type 1 ↓ the program responds with

DATE YYMMDD

which is a concatenation of the original data entered. To change this data, type in a new YYMMDD ↓. If no change is necessary simply type an ↓. If a mistake is made typing in a line, ending the line with !↓ will tell the program to ignore that line.

After all editing has been done, respond to line number with an ↓. The program then exists from the edit mode and goes to:

PRINTOUT (Y OR N)

5.3 TGM6C OPERATION

TGM6C is the data collection and reduction system for the Transit Track Geometry Measurement Vehicle.

The primary function of this program is to collect track geometry data, perform required data reduction on the data and output the results to a storage device.

The operation of the data collection system requires loading the header data tape and the TGM6C program.

The output data consists of a strip chart analysis of each channel, a magnetic tape which contains information from the header and the raw and processed data of a test run.

A secondary function of TGM6C is to validate the raw data from a test run and produce a strip chart analysis of the test.

EXECUTION

A. Test Setup

1. Mount TGM6C program tape on T1. (See Appendix I.)

2. Turn the POWER switch off and on to clear the Datum controller.

3. Set and start strip chart at a speed of 100mm per minute.

4. Set IOI interface switches as follows:

TEST - RPG to RPG (down)

S-T/T to T (up)

K to enable (down)

S/T to disable (up)

EVENT to disable (up)

SPARE (up)

B. Loading Procedure

1. Clear CPU using three clear switches.

2. Set MODE = RUN and P = 10.

3. Press START switch two times.

4. Remove TGM6C program tape and mount header data tape on T1.

5. Press START switch two times and remove HEADER tape from T1.

C. Data Collection

1. Mount data acquisition tape on T1. Ensure the magnetic tape write enable ring is present. Clear controller by pressing POWER switch two times.

2. Clear CPU using three clear switches.

3. Set MODE = RUN and P = 502.

4. Press START switch once. This should cause the core resident HEADER information to be written on the data collection tape and the CPU to stop. If this function fails to perform, it indicates a failure in the loading procedures or in the hardware. For a loading failure, reload starting at Step B.1; for a hardware failure, execute the system validation program.

5. The car is now in motion and ready to start data collection. Press the MASTER CLEAR switch on the IOI chassis and press the CPU START switch once.

As the car passes the next ALD (Automatic Location Detector), the chart recorder should start collecting data.

D. Program Errors

A failure to start usually indicates no RPG interrupts are being received. If the program starts but no velocity or profile data is output, then no DT's are being input from the time code generator. If the program stops during execution, the following program stops are built into TGM6C program. The P-register will contain the address at which the stop occurred.

P = 546	=	Power out of tolerance
P = 550	=	CP memory resume
P = 552	=	CP parity error
P = 554	=	CP instruction fault
P = 556	=	Privileged instruction error
P = 562	=	Executive call
P = 564	=	Real-time clock interrupts
P = 566	=	Interrupt clock interrupt
P = 574	=	Instruction fault

P = 576 = I/O data parity error

P = 670 = Vehicle speed greater than program ability to process data.

E. Run Termination

After all data for the run has been collected and the last ALD has been passed, the run is terminated.

1. Press STOP switch on CPU

2. Clear CPU using three clear switches

3. Set P = 504

4. Press START to write EOF on output tape.

If no more data is to be written on the output tape, repeat Steps 3 and 4 to write a second EOF.

F. Data Verification Operation

1. Mount the data collection tape on T1 and a tape on T2 if a copy of the original is desired.

2. Press three clear switches to clear the CPU.

3. Set MODE = RUN and P = 503, if a copy of the original is desired, or P = 505 if no copy is desired.

4. Turn the POWER switch off and on to clear the Datum controller.

5. Press CPU START switch three times. The first time will read HEADER from data tape. The second time will write HEADER on scratch tape. The third time will input data from test tape, reproduce strip chart analysis and output duplicate test data on scratch tape.

6. At the end of the data tape, the program will halt. If an output tape was generated, go to Section 5.3.E, Run Termination. Remove tapes and proceed to Step A.1 for next data collection test.

The execution of the validation procedure produces changes in the collection program core resident status which requires a total reloading of the system.

5.4 BRUSH RECORDER CALIBRATION PROCEDURE

The brush recorder calibration program (BRCAL) uses D/A outputs to hold constant values on all active channels. This allows manual adjustment of pen position.

The output values are selected by the program starting address as shown in Subsection C.

EXECUTION

A. Test Setup

1. Ensure the read/write ring is not present in BRCAL program tape.

2. Load BRCAL program on T1. (See Appendix I.)

3. Turn the POWER switch off and on to clear the Datum controller.

4. Set brush recorder speed to 25mm per minute.

B. Loading Procedure

1. Clear UNIVAC 1616 CPU using MASTER and REGISTER CLEAR switches.

2. Set MODE = RUN and P = 10.

3. Press the START/STOP switch once. The program should load from the magnetic tape and the CPU will halt at P = 51. If the program should fail to load, repeat loading procedure starting at Step A.2. If a hardware problem is suspected, run the system validation program and select the magnetic tape test (MT).

C. Executing Test

1. The output to the brush recorder is determined by the following starting addresses:

P = 600_8-output zeros - all pens should be on the right side of their scales.

P = 601-output ones - all pens should be on the left side of their scales.

P = 602-output step pattern - each pen will produce a step pattern.

P = 603-output will be the value present in RO.

2. All pens will continue outputting the set values until the CPU is stopped. The program may be restarted using the addresses in Step C.1.

APPENDIX A
HARDWARE SYSTEM DESCRIPTION FOR DATA ACQUISITION SYSTEM-1 (DAS-1)

1. DAS-1 HARDWARE

1.1 CONTROL PROCESSOR

The UNIVAC 1616 digital data computer, hereinafter referred to as the 1616, is the main processor for the data acquisition system. The 1616 is a general-purpose, modular, expandable computer.

The basic 1616 used in DAS-1 consists of a central processor, a memory containing 24,576 (24K) 16-bit words, and one Input/Output Controller (IOC) channel. All memory modules are directly addressable by the central processor control section. The IOC contains eight channels for DAS-1.

For control purposes, the IOC contains an internal (control) memory that is loaded under program control and is associated with referenced I/O channels. During operation, the contents of the memory section increments address information received from the data transfer control and stores it until it again needs to be incremented.

The main memory is a random access core memory with a 750 ns cycle time. The memory interface is an asynchronous request/knowledge type permitting operation with a memory of any speed. The memory operates independently of the Central Processor Unit (CPU) and IOC, having its own power supplies and cooling fans.

1.2 PRINTER

The VERSATEC Matrix Model LP1150 printer provides a means to print data received from the computer. The printer accepts asynchronous coded data in serial form and converts the codes to characters by means of a Read-Only Memory (ROM).

Electrostatic writing is accomplished by programming the voltage applied to a stationary linear array of conducting nibs to produce an invisible charge directly on the surface of dielectrically coated paper. The charge is developed by a liquid toner which produces a high-contrast, visible image of the data received.

1.3 MAGNETIC TAPE SYSTEM

The Bucode Model 4025 Magnetic Tape System (MTS) is designed for use in data storage and retrieval systems. Used in conjunction with a Datum Tape controller, the MTS provides the bulk-storage capacity for the DAS. The MTS is an industry standard, NRZI 9-track transport using 800 bpi and 100 ips while reading or writing and 50 ips during rewind.

1.4 DIGITAL-TO-ANALOG CONVERTERS AND RECORDER

The UNIVAC Digital-to-Analog Converters accept computer information via the IOI in the form of control words and data words. The control words are used to address the nine Digital-to-Analog Converters and channel 8-bit data bytes to the addressed DAC. The controller is capable of receiving and directing 300 data bytes per second per DAC. A tenth output consists of a computer generated pulse to the recorder.

The Gould Brush Model 481 Chart Recorder is an incremental drive recorder with eight signal channels and one timing channel. The recorder uses a pressurized ink writing technique over a 40mm wide graph for each signal channel. The timing channel uses the same writing technique but only uses 4mm between channels 1 and 2. The paper is advanced by a computer pulse-activated stepping motor. The chart advances a very precise and repeatable distance, resulting in extremely accurate chart positioning under computer control.

1.5 TELETYPE

The function of the Teletype ASR 35 typing unit is to enter and record in page printed form information received from a keyboard stroke or signal line code combination which represents characters or functions. The typing unit translates these code combinations into mechanical motions which imprint the message or initiate the indicated function. Printing is accomplished through an inked ribbon upon paper rolled around a horizontally stationary platen while the type and printing mechanism move from left to right across the page. All operations of the typing unit are performed automatically in response to input signal code combinations. Associated with the TTY is a paper tape reader/punch for reading or punching 8-level ASCII code.

1.6 MULTIPLEXER/ANALOG-TO-DIGITAL CONVERTER

The Zeltex (Redcor) Model 721 Multiplexer/Analog-to-Digital Converter (AD) contains two 16-channel multiplexer modules, controlled by a sequencer module. The sequencer, upon command, addresses the proper multiplexer data channel, and the multiplexed analog output is fed into a sample-and-hold amplifier module through a high input impedance buffer amplifier. The sample-and hold amplifier drives an analog-to-digital converter module that provides a digital output proportional to the analog input of the sample and hold. The analog-to-digital converter uses the successive approximation technique for comparing the analog data with a stable voltage reference. The two units have a combined capability of 200K conversions per second.

The IOI maintains two-way communication with two external A/D converters and sends a multiplexer address to the converters. When the conversion is complete, the converter places the digital data on the lines to the IOI. The IOI accepts the converted data and passes it on to the computer as either 8-bit or 12-bit words.

1.7 DISCRETE INPUTS

The UNIVAC Discrete Input Buffer connects the IOI with up to eight discrete devices (contact switches or TTL logic), each device providing 16 data bits to the IOI. On command from the computer, the IOI reads the data on the lines from a selected discrete device and sends the data on to the computer. The IOI sends no signals to the discrete devices. The IOI can also receive a discrete external interrupt request from an external equipment and pass the request on to the computer, along with an interrupt word from one of the eight discrete devices. A manual switch on the control panel also permits the operator to initiate an external interrupt to the computer. This unit is used to input data from a Time Code Generator, Distance Control and Event switches.

The Datum Model 9300 Time Code Generator produces a binary coded decimal signal representing the time of day, in hours, minutes, and seconds. This unit establishes the time reference for all tests. The coded time enters the computer memory via the Discrete Input Controller and is stored with each block of data as two 16-bit words. This unit also generates a crystal controlled 10 MHz clock used by the distance control unit.

The Distance Control unit accepts pulses from a rotary pulse generator and accumulates them, passing on to the computer a 16-bit word representing distance traveled. It also monitors the time between successive pulses and submits the Δt to the computer as a 16-bit speed word.

The third input to the Discrete Input Buffer is the Event switches. These consist of 16 remote toggle switches, of which some are controlled by the forward observer, and the others are controlled by the test conductor. The event switch boxes have an interrupt switch that causes the computer to sample the event switches on demand.

2. SYSTEM OPERATION

DAS-1 operates in a moving rail vehicle and is used to collect sensor data, convert it to 8-bit digital bytes or 12-bit words and process it in a 16-bit word computer. The computer in turn provides outputs in the form of a format compatible with magnetic tape storage, a teleprinter, an 8-channel chart recorder, and a line printer.

The test data are picked up by sensors which input to the multiplexer. Here, the signals are switched and held to fixed voltage levels, which in turn are sampled by an Analog-to-Digital Converter (AD) under control of the distance block or a sampling clock which establishes the sample time. The AD is under program control and is addressed and controlled via the Input Output Interface (IOI). The 8-bit or 12-bit digital data from the AD is sent through the high-speed IOI to the main memory of 24K words. While data are being stored in memory, the computer program can analyze and derive new data for storage. When a record of data has been assembled in memory, the program initiates a transfer to a MTS via the IOI.

The results of the analysis performed in real-time are transferred to a set of 8 Digital-to-Analog Converters, each of which drives one input to an 8-channel chart recorder. A unit distance pulse or the sampling clock is used to incrementally advance the recorder, allowing all readings to be directly related to distance or time. This information together with the raw data is duplicated on the magnetic tape storage to be used in summaries during on-board post processing, thus allowing complete analysis and printout shortly after a run is completed.

The system can be loaded from punched paper tape and/or the magnetic tape system, after which software and TTY inputs control the data acquisition.

The Discrete Signal Controller is used to accept inputs from a Time Code Generator and other discrete switch inputs. These signals are used to synchronize tests and control system functions using a hardware interrupt scheme.

APPENDIX B

INTEGRATION AND SMOOTHING, AND MIDCHORD ALGORITHMS

SMOOTHING ALGORITHM

The algorithm for the double integration is:

1. AS = r*AS+a_t.
2. NA = r*NA+1
3. AA = AS/NA
4. AP = a_t-AA
5. V = r*V+AP*τ
6. VS = r*VS+V
7. NV = r*NV+1
8. VA = VS/NV
9. VP = V-VA
10. D = r*D+VD*τ

where: a_t is the output of the accelerometer,

τ is the time interval between readings,

r is a time constant of integration equal to $(1-\varepsilon)$,

ε is 2^{-n}, and

all variables are initialized to 0.

The smoothing algorithm is:

1. i = i+1
2. if i>N then i = 1
3. MA = MA + D/N - A(i)/N
4. A(i) = D
5. j = i-N/2
6. if j<1 then j = j+N
7. TP = A(j)-MA.

MIDCHORD ALGORITHM

Midchord Alignment and Profile

Midchord profile may be defined as shown in Figure B-1. A chord of length ℓ is stretched between two points on the rail. The displacement, h, of the mid-point of this chord from the rail (i.e., the mid-ordinate-to-chord displacement) is defined as midchord profile. Midchord alignment is defined in a similar manner.

These parameters as defined are measured directly by the familiar stringlining of a rail which, with other forms of mid-ordinate-to-chord measurements, has been a traditional railroad technique.

Stringlining derives its name, of course, from the use of a string stretched between two points on the rail to represent the chord. Then the displacement of the mid-point of the string from the rail can be measured. The common chord length that has been used is 62 feet which is a convenient choice for measurement of curvature because the 62-foot mid-oridinate-to-chord measurement in inches is equal to the curvature of the track in degrees. Variants of the 62-foot chord have been a 31-foot chord, which was one quarter of the response of the longer chord, and a 44-foot chord, which has one half the response. We understand that the 44-foot chord has been used for measurement of sharp curves -- 5 degrees or more. It is quite uncommon.

Midchord data contains two spurious half amplitude perturbations half a chord length away for each discrete track perturbation. In addition it is blind to periodic perturbations with wavelengths of $\ell/2n$ for $n = 1, 2, \ldots$, where ℓ is the chord length (beam or stringline). These characteristics contribute to the difficulty in conversion of data from one chord length to another. "True profile" data, on the other hand, can be readily converted to midchord data of any desired chord length including the 62-foot chord currently used for track classification.

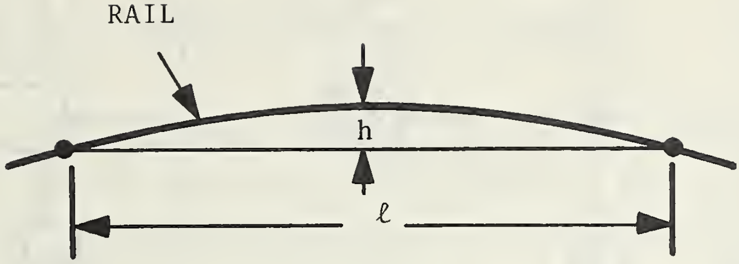


FIGURE B-1. DEFINITION OF PROFILE

The midchord algorithm (see Figure B-2 uses three points X_i, X_m, and X_{i+62} where X_m is the midpoint of the 62-foot chord bounded by X_i and X_{i+62}. The output of the algorithm is then

$$X_c = X_m - \frac{X_i + X_{i+62}}{2}$$

The indexing for midchording will use 128 points which results in a distance of approximately 62 feet.

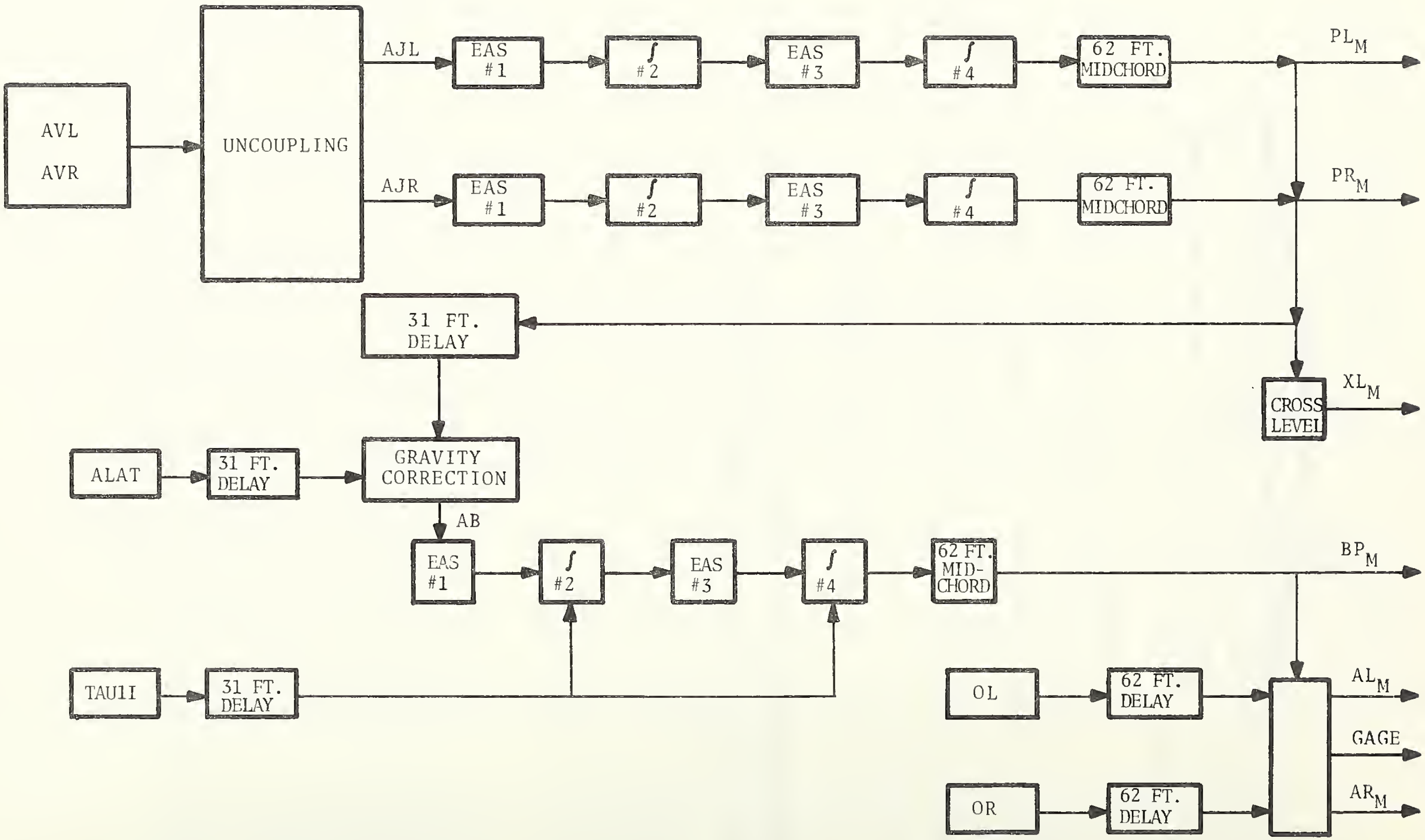


FIGURE B-2. MIDCHORD ALGORITHM

APPENDIX C

MODIFICATIONS TO IOI MODULE

This appendix describes the function of the modifications incorporated into the discrete input controller such that asynchronously timed inputs are interfaced to the controller and a priority of interrupts is established.

The capability now exists to identify the source and priority of up to four interrupts and to accept up to seven asynchronously timed inputs.

These features although primarily directed at satisfying the requirements of a track geometry system do not entirely preclude use with general vehicle test instrumentation provided that certain restrictions are noted.

When used with the track geometry system, the following subchannel assignments must be observed with regard to both hardware and software:

0 empty

1 time code generator bit 00-15 } the cycle bit should be used here

2 time code generator bits 16-31 } the cycle bit should be used here

3 gage bits 00-07 and 08-15 (planned)

4 distance/time accumulator (is presetable and its overflow is detectable)

5 event bits 00-07/bits 08-14; ALD bit 15

6 interrupt identification bits 00-07

7 empty.

Present plans for satisfying the requirements for general vehicle testing which differ from those of track geometry consists of multiplexing the data from the six rotary pulse generators (MPG) onto subchannel 3 via an external module. This module has not been designed thus far.

When the computer channel 4 interrupt line is enabled any one of four devices can, according to the priority indicated below, cause an interrupt to be generated. The source of the interrupt is identified by examining subchannel 6 using the word format as shown in Table C-1. Any or all of the sources of interrupt can be disabled via a switch.

1. Rotary Pulse Generator (RPG) accumulator (÷K) overflow
2. Event
3. Distance/Time ($\Delta S/\Delta T$) accumulator overflow
4. Front panel switch.

It should be noted that in order to reset the condition which allows interrupts, the interrupt must be disabled after initiating the handler and reenabled before exiting the routine.

TABLE C-1. WORD FORMATS

TCG input	seconds				milliseconds											
	8	4	2	1	800	400	200	100	80	40	20	10	8	4	2	1
subchannel No. 1	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

TCG input	hours						minutes							seconds		
	20	10	8	4	2	1	40	20	10	8	4	2	1	40	20	10
subchannel No. 2	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Gage input	binary gage left								binary gage right							
	7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0
subchannel No. 3	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Distance/time accumulator input	binary increments of distance or number of lapsed microseconds															
	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
subchannel No. 4	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Event input/ALD	ALD for track geometry	event identifier							event class/type							
	X	40	20	10	9	4	2	1	7	6	5	4	3	2	1	0
subchannel No. 5	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

An example of how these event bits might be used follows:

0 entering station
1 leaving station
2 switch
3 guard rail left
4 guard rail right
5 enter crossing
6 leave crossing
7 miscellaneous to be indexed by identifier.

Interrupt identification	input not used												identifier bit			
subchannel No. 6	X	X	X	X	X	X	X	X	X	X	X	X	3	2	1	0
	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

0 RPG÷K overflow
1 Event
2 ΔS/ΔT accumulator overflow
3 Front panel switch

APPENDIX D
GAGE DEGLITCHER

A Δ criterion for allowable change in OL and OR from sample to sample.

if $|OL_{n+1} - OL_n| \geq 0.025$ in.

set $OL_{n+1} = OL_n + \text{Sgn}\,(OL_{n+1} - OL_n)(0.0125 \text{ in.})$

if $|OL_{n+1} - OL_n| < 0.025$ in.

Let $OL_{n+1} = OL_{n+1}$

since the LSB for OL and OR input is 0.00003817 inch, we get

0.025 in. = 01216

0.0125 in. = 0507

APPENDIX E
GRAVITY CORRECTION ALGORITHM

The purpose of the gravity correction algorithm is to remove from the lateral accelerometer output the component of gravity which arises whenever the train (truck) tilts relative to the vertical, resulting in a non-horizontal (input axis) accelerometer.

The gravity correction term is given by the following expression:

$$GR \ SIN \ [XL/(G+2)]$$

where:

GR = free-fall acceleration caused by gravity at sea level

= 386 in/sec^2

XL = difference between left and right profiles

= $\pm$4 inches (maximum)

G = gage length, as before in the accelerometer uncoupling algorithm.

Here again it has been decided to use a constant value for the gage length (G) of 56.5 inches. The errors introduced by this simplification can be shown by the following expressions.

for:

G = 56 inches, XL = 4 inches

XL/(G+2) = 0.0689 (3.96 deg.)

G = 58 inches, XL = 4 inches

XL/G+2) = 0.0666 (3.82 deg.)

Here again, the maximum variation is about 4 percent. Using a midrange value for G (57 inches) would yield a worst case error of 2 percent; and, in general, the error would be much smaller during a typical run.

The gravity correction term has been expressed as:

$$\left(\frac{GR}{G+2}\right)XL$$

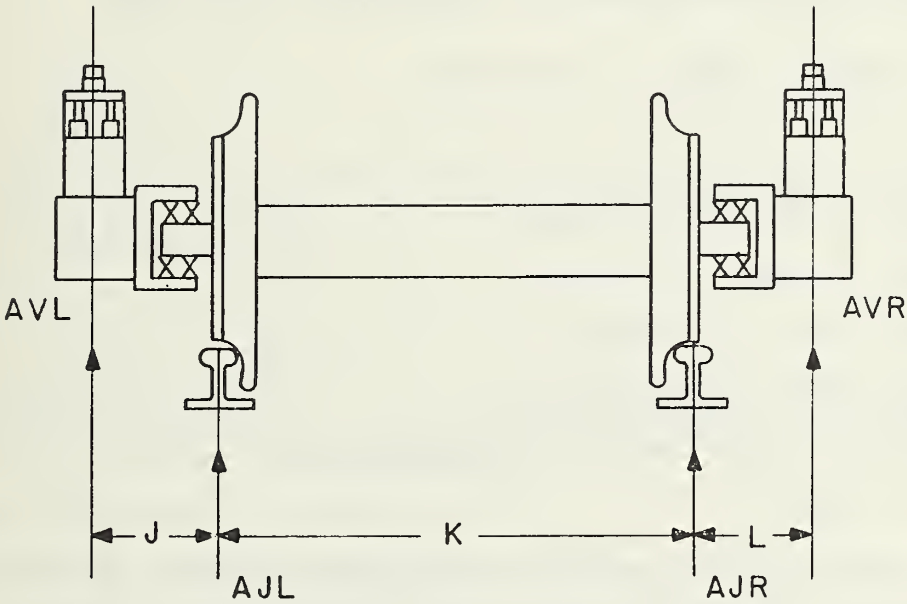
where G and GR are constants. Note that the above utilizes the fact that for small angles sin X = X is expressed in radians.

In the implementation of the above expressions in the computer program, the parameter of GR/(G+2) = GGR will be entered as initial condition through the keyboard.

APPENDIX F

UNCOUPLING VERTICAL ACCELEROMETER SIGNALS

The sketch shows the arrangement for profile measurement accelerometer located "outside" the rails. K is the distance between wheel/rail contact points and is approximately equal to track gage plus 2 inches. J and L are the distances the accelerometers are located outside these wheel/rail contact points. The distance J+K+L is a constant.



For positive accelerations, AJL and AJR imparted by the rail to the wheel, the sensed accelerations are given by

$$AVL = \frac{J+K}{K}(AJL) - \frac{J}{K}(AJR)$$

$$AVR - \frac{L}{K}(AJL) + \frac{K+L}{K}(AJR)$$

The journal box acceleration in terms of the sensed accerations are

$$AJL = \frac{K+L}{J+K+L} (AVL) + \frac{J}{J+K+L} (AVR)$$

$$AJR = \frac{L}{J+K+L} (AVL) + \frac{J+K}{J+K+L} (AVR)$$

If it can be assumed that J=L to a reasonable degree of approximation and that the variations in track gage are reasonably small, constant coefficients can be used in the above equations. It has been shown previously that the worst case errors resulting from the above assumptions are on the order of 1 percent. The above equations can be simplified for computation by letting

$$H = \frac{J}{J+K+L} = \frac{L}{J+K+L} = \text{a constant.}$$

Then

$$AJL = (1-H)\ AVL + H\ (AVR)$$

$$AJR = H\ (AVL) + (1-H)\ AVR$$

$$AJL = AVL - H\ (AVL-AVR)$$

$$AJR = AVR + H\ (AVL-AVR)$$

The value of H used (for the R-42 vehicle) is

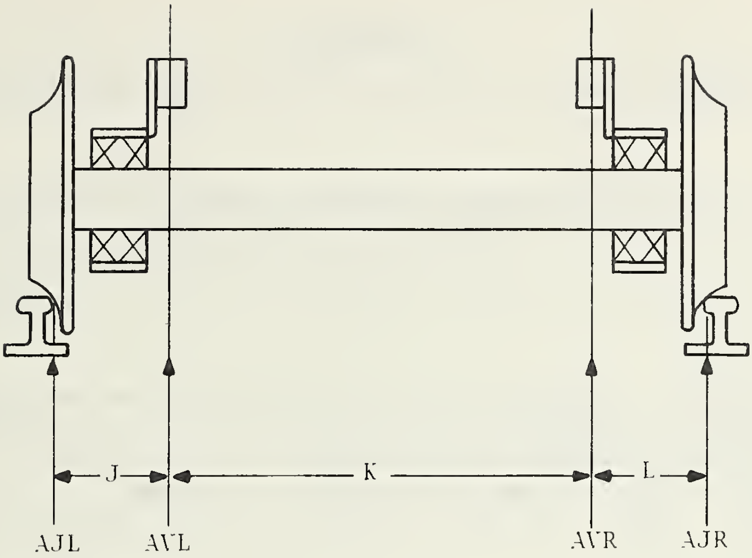
$$H = 0.175$$

The sketch on the next page shows the situation for the journal boxes and profile measurement accelerometers located "inside" the rails. In this case, K, the distance between accelerometer input axes, is constant and the sum, J+K+L, is equal to track gage plus 2 inches.

For positive accelerations, AJL and AJR, imparted by the rails,

$$AVL = \frac{K+L}{J+K+L} (AJL) + \frac{J}{J+K+L} (AJR)$$

$$AVR = \frac{L}{J+K+L} (AJL) + \frac{K+L}{J+K+L} (AJR)$$



The journal box accelerations in terms of sensed accelerations are

$$AJL = \frac{J+K}{K} AVL - \frac{J}{K} AVR$$

$$AJR = -\frac{L}{K} AVL + \frac{K+L}{K} AVR$$

It is again assumed that J = L a constant, letting $H = \frac{J}{K} = \frac{L}{K}$ permits the following simplification:

$$AJL = (1+H)\ AVL - H\ (AVR)$$

$$AJR = -H\ (AVL) + (1+H)\ AVR$$

$$AJL = AVL + H\ (AVL-AVR)$$

$$AJR = AVR - H\ (AVL-AVR)$$

For the Toronto H4 vehicle, K = 34-7/8" and J = L = 13". Hence,

$$H = \frac{J}{K} = 0.373$$

For the simplified version of the uncoupling equations, observe that the only difference between the two cases of accelerometer location with respect to the rails, is the interchange of a plus and minus sign.

APPENDIX G

CONTROL WORDS AND LSB'S FOR A/D, D/A, AND MAGNETIC TAPE

The D/A control words and LSB's used for output to the Brush Recorder are:

a. Data Word

BIT POSITION	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DESIGNATOR	← VOLTAGE →								NOT USED				SUBCHANNEL DESIGNATOR			

b. Voltage Designator

BIT POSITION		15	14	13	12	11	10	9	8
+FS-1LSB	+2.48046875	1	1	1	1	1	1	1	1
+1/2FS	+1.25000000	1	1	0	0	0	0	0	0
+LSB	+0.01953125	1	0	0	0	0	0	0	1
ZERO	0.00000000	1	0	0	0	0	0	0	0
-LSB	-0.01953125	0	1	1	1	1	1	1	1
-1/2FS	-1.25000000	0	1	0	0	0	0	0	0
-FS+1LSB	-2.48046875	0	0	0	0	0	0	0	1
-FS	-2.50000000	0	0	0	0	0	0	0	0

c. Subchannel and Control Designator

BIT POSITION	3	2	1	0
SUBCHANNEL 0	0	0	0	0
SUBCHANNEL 1	0	0	0	1
SUBCHANNEL 2	0	0	1	0
SUBCHANNEL 3	0	0	1	1
SUBCHANNEL 4	0	1	0	0
SUBCHANNEL 5	0	1	0	1
SUBCHANNEL 6	0	1	1	0
SUBCHANNEL 7	0	1	1	1
SUBCHANNEL 8	1	0	0	0
CONTROL	1	0	0	1

The control and status words for magnetic tapes follow:

a. Control Words

COMMAND	BIT POSITION 16 15 14	BIT POSITION 13 12 11 10 9 8 7 6 5 4 3 2 1 0
WRITE ONE FILE MARK		0 ←→ 0 1
WRITE ONE RECORD		0 ←→ 0 1 0
READ ONE RECORD		0 ←→ 0 1 0 0
REWIND TAPE		0 ←→ 0 1 0 0 0
FORWARD SPACE ONE RECORD		0 ←→ 0 1 0 ←→ 0
REVERSE SPACE ONE RECORD		0 ←→ 0 1 0 ←→ 0
WRITE THREE INCH GAP	NOT USED	0 ←→ 0 1 0 ←→ 0
NOT USED		X ←→ ←→ X
READ STATUS		0 ←→ 0 1 0 ←→ 0
SELECT TAPE TRANSPORT		0 ←→ 0 1 0 ←→ 0
TAPE UNIT SELECT (BIT 1-2^0)		0 0 0 1 0 ←→ 0
TAPE UNIT SELECT (BIT 2-2^1)		0 0 1 0 ←→ 0
SELECT EVEN PARITY		0 1 0 ←→ 0
SELECT LOW DENSITY		1 0 ←→ 0

b. Status Words

WORD	15 14 13 12 11 10	9 8 7 6 5 4 3 2 1 0
ERROR		0 ←→ 0 1
END OF TAPE		0 ←→ 0 1 0
BEGINNING OF TAPE		0 ←→ 0 1 0 0
REWINDING		0 ←→ 0 1 0 ←→ 0
FILE MARK	NOT USED	0 ←→ 0 1 0 ←→ 0
PARITY ERROR		0 ←→ 0 1 0 ←→ 0
NOT USED		X ←→ X
REJECT		0 0 1 0 ←→ 0
ODD LENGTH RECORD		0 1 0 ←→ 0
CONTROLLER BUSY		1 0 ←→ 0

A/D Control and data word formats

a. Control Word

BIT POSITION	15 14 13 12 11 10 9 8	7	6 5	4 3 2 1 0
DESIGNATOR	NOT USED	*		SUBCHANNEL

*MODE 1 = HALF WORD
0 = FULL WORD

b. Subchannel Identifiers

BIT POSITION		4	3	2	1	0
SUBCHANNEL	00	0	0	0	0	0
	01	0	0	0	0	1
	02	0	0	0	1	0
	03	0	0	0	1	1
	04	0	0	1	0	0
	05	0	0	1	0	1
	06	0	0	1	1	0
	07	0	0	1	1	1
	08	0	1	0	0	0
	09	0	1	0	0	1
	10	0	1	0	1	0
	11	0	1	0	1	1
	12	0	1	1	0	0
	13	0	1	1	0	1
	14	0	1	1	1	0
	15	0	1	1	1	1
	16	1	0	0	0	0
	17	1	0	0	0	1
	18	1	0	0	1	0
	19	1	0	0	1	1
	20	1	0	1	0	0
	21	1	0	1	0	1
	22	1	0	1	1	0
	23	1	0	1	1	1
	24	1	1	0	0	0
	25	1	1	0	0	1
	26	1	1	0	1	0
	27	1	1	0	1	1
	28	1	1	1	0	0
	29	1	1	1	0	1
	30	1	1	1	1	0
	31	1	1	1	1	1

c. Voltage Designators

BIT POSITION		11	10	9	8	7	6	5	4	3	2	1	0
+FS-LSB	+4.997500	0	1	1	1	1	1	1	1	1	1	1	1
+1/2FS	+2.500000	0	1	0	0	0	0	0	0	0	0	0	0
+3/8FS	+1.875000	0	0	1	0	0	0	0	0	0	0	0	0
+LSB	+0.002440	0	0	0	0	0	0	0	0	0	0	0	1
ZERO	0.000000	0	0	0	0	0	0	0	0	0	0	0	0
-LSB	-0.002440	1	1	1	1	1	1	1	1	1	1	1	1
-3/8FS	-1.875000	1	1	0	1	0	0	0	0	0	0	0	0
-1/2FS	-2.500000	1	1	0	0	0	0	0	0	0	0	0	0
-FS+LSB	-4.997500	1	0	0	0	0	0	0	0	0	0	0	1
-FS	-5.000000	1	0	0	0	0	0	0	0	0	0	0	0

d. Data Word Formats

	15 ... 4	3 ... 0
FULL WORD	12-BIT DATA WORD	—

	15 ... 8	7 ... 0
HALF WORD	—	8-BIT DATA WORD

APPENDIX H
GLOSSARY OF TERMS

SYMBOL	DEFINITION
AB	Beam lateral acceleration
ABSF	Lateral accelerometer scale factor to compensate for the difference between actual scaling and ideal
AJL	Left journal vertical acceleration
AJR	Right journal vertical acceleration
AL	Left alignment
ALD	Automatic location detection
AR	Right alignment
AVL	Acceleration, left vertical
AVLH	Acceleration, left vertical (high frequency)
AVLSF	Left vertical accelerometer scale factor to compensate for the difference between actual scaling and ideal
AVR	Acceleration, right vertical
AVRH	Acceleration, right vertical (high frequency)
AVRSF	Right vertical accelerometer scale factor to compensate for the difference between actual scaling and ideal
BD	Distance, ALD detector to axle ℄
BEAM	Distance, between gage probe zero references
BG	Distance, gage probe to axle ℄
BP	Beam lateral position (or displacement)
BV	Distance, sensor beams to axle ℄
CL	Left capacitive gage probe output
CR	Right capacitive gage probe output
D	Distance along track from reference

SYMBOL	DEFINITION
DAS	Data acquisition system
DC	Distance correction to shift zero of D
DCD	Distance correction to ALD data
DCG	Distance correction to gage probe data
DCV	Distance correction to vertical accelerometer data
DMA	Moving average distance delay
E	Correction factor for lateral position of vertical accelerometer
EM	Event marker
FCH	High cutoff frequency, cy/ft
FCL	Low cutoff frequency, cy/ft
G	Track gage, inches
GR	Gravitational acceleration
H	Correction factor for lateral position of vertical accelerometer
HA	High limit on alignment tolerance
HG	High limit on gage tolerance
HP	High limit on profile tolerance
HS	Horizontal scale factor for chart records
HX	High limit on cross-level tolerance
LA	Low limit on alignment tolerance
LC	Length of chord
LG	Low limit on gage tolerance
LP	Low limit on profile tolerance
LX	Low limit on crosslevel tolerance
MA	Maximum ordinate for alignment

SYMBOL	DEFINITION
MCD	Midchord indicator that determines what type of profile data will be output by TGM6C. 0-true profile. 1-midchord profile. 2-both with no alignments.
MD	Maximum ordinate for ALD
MG	Maximum ordinate for gage
MP	Maximum ordinate for profile
MS	Maximum ordinate for speed
MX	Maximum ordinate for cross level
NA	Minimum ordinate for alignment
ND	Minimum ordinate for ALD
NG	Minimum ordinate for gage
NP	Minimum ordinate for profile
NS	Minimum ordinate for speed
NX	Minimum ordinate for cross level
OL	Left optical gage probe signal
OLSF	A scale factor to compensate for the difference between the actual gage sensor scaling and the ideal of ±5 V corresponding to ±1-1/4 inch.
OR	Right optical gage probe signal
ORSF	Same as OLSF
PL	Left profile
PR	Right profile
RPG	Rotary pulse generator output
S	Vehicle speed, ft/sec
SDF	Spatial data filter
SF	Scale factor
T	Time

SYMBOL	DEFINITION
TD	Time delay in ALD sensor
TDI	Time delay in integration process
TFD	Time delay in filter for ALD data
TFG	Time delay in filter for gage data
TFLAT	Time delay in filter for lateral acceleration data
TFV	Time delay in filter for vertical acceleration data
TG	Time delay in gage sensor
TI	Integration time constant (equivalent)
TLAT	Time delay in lateral accelerometer
TSD	Time delay in sampling and A/D conversion of ALD data
TSG	Time delay in sampling and A/D conversion of gage data
TSLAT	Time delay in sampling and A/D conversion of lateral accelerometer data
TSV	Time delay in sampling and A/D conversion of vertical accelerometer data
TV	Time delay in vertical accelerometer
VS	Vehicle speed
WC	Wheel circumference
WFC	Wheel circumference factor
XL	Cross level

APPENDIX I
SELECTION OF TAPES

On the controller are four switches labeled A, B, C, D. MTU0 is associated with switch A, MTU1 is associated with B, and if the system has three tapes, MTU2 is associated with C. Each of the switches A, B, C, D may be put in one of four positions labeled 0, 1, 2, 3. No two switches may be in the same position, otherwise tape errors may result. One of the switches will be at position 0. The tape associated with the position zero switch is T1. The tape associated with position 1 switch is T2.

If the system has three tapes, the tape associated with the switch in position 2 is T3, e.g., if A=1, B=0, C=2, D=3, then MTU0 is T2, MTU1 is T1, MTU2 is T3.

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