CHAPTER 137

COMPUTER CONTROL AND DATA ACQUISITION OF A TIDAL MODEL

by

E.R. Funke*

ABSTRACT

A large tidal model of the St. Lawrence River covering the region from Montreal to Ile du Bic is connected directly to a mini computer for data acquisition and control of the tidal boundary. Some of the more important concepts for the design and operation of a computer based system for this application are described. Details of an adaptive feedback controller for diurnal tides are given.

A 16 mm film (N.R.C.-Division of Mechanical Engineering, film no. HYP 620, same title) describes the instrumentation and operation of the model. A report (N.R.C.-Division of Mechanical Engineering, Report No. MH-110, same title) provides further details of this system.

THE MODEL AND THE COMPUTER HARDWARE

The National Research Council under the sponsorship of the Ministry of Transport is operating a 750 ft tidal model of the St. Lawrence River covering a 325 mile section of the river from Montreal to Ile du Bic. The model has a horizontal scale of 1:2000 and a vertical scale of 1:120. Steady but adjustable tributary inflows are provided at various upstream locations. The model has one tidal boundary and a digital computer is used to control this boundary over one repeating diurnal cycle by means of a 35 cfs axial flow impeller pump. In addition one may use three 10 ft long weirs in this control which do not, however, significantly improve performance of the tidal control scheme.

The computer is an Electronics Associates Inc. EAI 640 with 16K words of 16 bit core, 1.65 microseconds cycle time, 2 disc drives, a teletype writer, a card reader, a drum plotter and a small magnetic tape recorder. In addition, there is an analog to digital interface with 96 single ended analog input and 8 analog output channels, 16 output control lines, 8 sense lines, 8 general-purpose interrupts and a digital timer.

Associate Research Officer, National Research Council, Ottawa, Ontario, KlA 0R6.

THE ACTIVATORS

Pitch control of the tidal pump is primarily affected by a hydraulic feedback controller. The pilot valve of this controller is connected to a stepping motor through a precision screw drive. This stepping motor is driven directly by two output control lines from the digital computer. Similarly, stepping motors are attached to their weirs through screw drives and these motors are also driven through separate output control lines.

THE TRANSDUCERS

There are 48 floating bulb water level gauges (N.R.C. -Division of Mechanical Engineering, LTR-HY-30, "A Laboratory Type Water Level Gauge", J. Ploeg) and up to 20 velocity meters (N.R.C. - Division of Mechanical Engineering, LTR-HY-29, "A Drag Plate Velocity Meter for Use in Hydraulic Laboratories", B.D. Pratte, September 1972) are installed along the model. These are designed around Hewlett-Packard linear differential transformers. The level gauges are located in the model in the same geographic areas as tidal recording stations on the river. In addition to the measurement transducers there are several devices used for the monitoring of various operational and fault conditions. These include: -weir position, -pitch position, -weir or pitch limits, -power failure, -low hydraulic pressure, -butterfly or gate valve open or closed, -pump flow in or out, and others. Up to 6 multi-turn, manually operated potentiometers are provided which may be programmed to permit operator intervention in the functions of the control program.

OPERATIONAL FEATURES PROVIDED BY THE COMPUTER SOFTWARE

The computer software is almost entirely written in FORTRAN IV. It performs three distinct <u>on-line</u> functions; -the control of the tidal boundary, -the acquisition of measurement data and -the optional display of some data. These functions include the following features; -independent open loop control of three weirs, -control of one tidal pump by means of a feedback control function and a pump control table, -ability to evolve this pump control table, -monitoring and optional reporting of various fault conditions such as limits and jams, -data acquisition of 96 analog channels and 8 sense lines and their conversion to physical variables, e.g. levels to inches, currents to inch/sec and status to 'fault' or 'no fault', -storage on disc of converted data for the last 2 diurnal cycles,-calculation of tidal extremes over last diurnal cycle and mean discharges for up to 15 stations from current, elevation and cross-section area information, -the optional plotting of instantaneous water surface profiles and the optional typing of discharges or tidal extremes.

In the off-line mode the computer may be used to perform the following: -the optional smoothing of the pump control table by means of a Fourier transform algorithm, - the generation by means of a Fourier transform algorithm of a tidal profile over a diurnal cycle of 612 points using hourly readings as an input, -initialization of the control program including the calculation of head over weirs for any given overflow and the subsequent setting of the weirs to this elevation, -the facility to read and write various fixed parameters and control profiles via typewriter, card reader and magnetic tape, -the display by plotter of all experi-mental data. During run time the tidal elevations and velocities are stored on disc as blocks representing a scan The output program can select from one block, of all gauges. data from any number of level gauges and plot these as a function of distance from upper end of model or pick one gauge from all blocks and plot its output as a function of time. The tidal extremes may be plotted as a function of distance from upper end of model representing the envelope of tidal excursions for the entire river), -the plotting of a grid system as a function of distance from upper end of model, -the calibration of level gauges. (This feature provides for the automatic setting of weirs to a predetermined level and after excess water has run off and the model has settled, the program will take 50 consecutive readings over 40 seconds, and compute the average voltages and their standard deviations. This output represents one point on the calibration curve of all gauges. Repeated application of this procedure at different levels makes up a complete calibration run), -a quick check for all level gauges. (This is provided by computing the mean elevation of all gauges with the use of present calibration constants. Any gauge that is significantly out of calibration will reveal itself readily in comparison to all other gauges.)

DESIGN CONCEPTS FOR THE SOFTWARE SYSTEM

The Transducer Card

The transducer card is an IBM punched card associated with each transducer, potentiometer or switch and which contains all pertinent information such as station name, its analog channel number and its calibration constants. In addition there is a 'formula type number' which defines the particular conversion formula applicable to this transducer and, consequently, the manner in which the various constants are to be used. For example, a level gauge is converted according to y = (v - B)/A + M and a velocity gauge is converted as $u = \text{sign}(A) \cdot \text{sign}(v) \cdot \sqrt{|v|/|A|}$, where v is the voltage reading, B is a bias voltage at mean water level, A is the sensitivity constant and M is the mean water level relative to datum. Both velocity and level gauges carry one constant D as a distance in miles from Montreal. This permits the plotting of water surface profiles and the interpolations of elevations associated with discharge calculations. The conversion program currently in use handles up to 8 formulas, most of which are related to fault detection transducers.

Scale Factors and Data Types

Although conversion arithmetic is executed in floating point, for reason of economy all constants and variables are carried in storage in integer format. This leads to a choice of dimensions of variables suitable for this requirement, e.g. voltage readings are in millivolts, elevations are in inch/1000 and velocities are in (inch/1000) per second. The dimensions of some calibration constants are chosen to give at least 3 figure accuracy as, for instance, the constant A for level gauges which is in millivolts per inch. Dimensions of converted variables are usually carried in model units as this facilitates the evaluation of experimental data. However, at the time of final output of the measurement data, this is converted to prototype dimensions. This principle is, however, adaptable. The main objective is to reduce the amount of operator effort and if, for example, the run time calculations of discharges are more meaningful to the operator if carried in prototype units, then this will in fact be done.

Operator Control of Programs

The programs are packaged into 6 units. Each unit nearly fills the available core memory and includes a number of the described tasks. Each task is accessible to the operator through the typing of a one or two digit number which will cause the program to branch to the selected task. For the output program a control card is used to select a particular function and to specify pertinent parameters for this purpose. Consequently, the operator can prepare a deck of control cards that will cause the computer to carry out a pre-selected sequence of events. This control card is sufficiently simple to prepare so that the operator will not require any particular programming knowledge to modify it.

The Feedback Control Scheme for the Tidal Model

The feedback controller for this tidal model is basically a proportional plus derivative controller which is, however, augmented by an adaptive scheme. The fact that the tidal profile is repetitive is used to advantage, and the control scheme is programmed to learn from past mistakes and to take appropriate corrective action at an early enough time in the next tidal cycle.

The schematic of the control scheme is illustrated in

Fig. 1. In this diagram, the tidal profile, which exists in the computer as a table of numbers, is represented as a cam. As this hypothetical cam rotates, the corresponding movement in the computer is the stepwise incrementation of the table index every 0.8 seconds.

The reference input is taken from the 'cam' at a particular phase. This is compared to the water elevation at the control point, which is a gauge near the lower boundary of the model. This control transducer is substantially the same as the ones used for general data acquisition. The only difference is the choice of the linear differential transformer which has a ±3 inch range while most other transducers have a ±2 inch range. It is necessary to have an instrument with a large deflection range as there is a distinct danger that the water elevation might exceed these limits with a subsequent loss of signal. If this happens, the computer may compute an error of the wrong polarity and the system would then go completely out of control.

The transducers with a larger range have smaller resolution and accuracy in terms of absolute value. A typical figure quoted by Hewlett-Packard is .5%, which corresponds to an error due to non-linearity and resolution of .015 inch. Careful calibration will reduce this figure to .005 inch. So far the model control has proved adequate for the measurements that are being made. However, if it should become necessary to improve the accuracy of the feedback control, one may double up on the feedback transducer, one for fine control over the normal operating range and the other for coarse control in the fringe areas.

The areas in Fig. 1, which are surrounded by dashed/dotted lines, represent the jobs carried out by the various subroutines. In the normal feedback control situation the switch S_H is closed and S_G is open. The control function that is computed by the subprogram FDBCTR is based on present and previous errors and is given by

$$IEU_{i} = A_{0} * (E_{i} + E_{i-1})/2 + A_{1} * (E_{i} - E_{i-2})/2\Delta T.$$

The program remembers past values of error but discards those beyond $(i-2)\Delta T$.

Manual potentiometers are available to control the coefficients A_{0} and A_{1} . These 3-turn potentiometers are programmed through their transducer cards to give an output of one when turned fully clockwise and zero when turned fully counter clockwise. At the present time values of A_{0} = .067 and A_{1} = .05 are used with the dimension of E being in inch/1000 and ΔT = 0.8 seconds.

The feedback controller alone is not adequate for satisfactory operation. With the selected loop gains, control errors in the order of 0.1 inches are normal. Increased loop gains lead to instabilities. More sophisticated control functions which are designed around a lumped parameter approximation of the tidal basin proved critical. These lead to instabilities that are imperceptible at the control point but become undesirably amplified at several upstream locations with shallow water depth.

The method that is now being used with considerable success is based on the principle that a feedback controller should overcome primarily the unpredictable element in the control objective. Anything that is known a priori about the control task should not be achieved by the feedback error control. Rather, one should attempt to regulate the system as well as possible through an open loop control and whatever errors are made in this effort, due to random disturbances or misjudgement of system parameters, can then be corrected for by the feedback controller.

The open loop controller that is required here is a profile of control signals to the tidal pump that will regulate the impeller pitch to cause flow in and out of the tidal basin in such a way that the water elevation at the control point corresponds to the reference input. This profile is not easily determined by theoretical considerations or measurement. As a matter of fact, it was found that the simple placement of several roughness elements at certain places in the river model gave an almost imperceptible local change in water level, but could cause a major effect on the pump control profile. In addition, the pump has a nonlinearity in the vicinity of zero pitch which behaves more or less like a 'dead zone'. This nonlinearity is also a function of the head difference between the model and the sump which is variable. In the presence of these difficulties is was thought best to devise a scheme that would generate the required pump control profile through a learning procedure. This option is activated by closing S_G in Fig. 1.

When the controller recognizes an error and computed the corresponding control function IEU, then it is assumed that this corrective action, which is taken now, could yield better results if it had been taken a little sooner. For this reason, the quantity IEU_1 is added to the pump control profile at a point just ahead of the current table index 'i'. If the pump control profile is $ITBL2C_1$ and the present value of the control function is IEU_1 , then the learning function is expressed as

ITBL2C_{i-j} next cycle = ITBL2C_{i-j} + SO*IEU_i

where SO is an adjustable gain constant which is now always set to 1 and j is an adjustable phase control constant which is now set to 5 seconds/.8 seconds = 6 steps. Care is taken of course to recycle the index whenever table limits are exceeded.

When control conditions are changing or a new tidal profile is required, then it is necessary to place the computer system into this adaptation mode by closing the switch S_G . This is referred to as the 'updating' of the pump control profile. This procedure may take up to 8 diurnal cycles until the error has vanished to acceptable limits. After this it is customary to store all control parameters, including the tidal profile and the pump control profile, on digital magnetic tape. This allows the operator to recall from tape any particular tide which has been run previously and put the model into operation within minutes. Start-up transients at the control point for fully updated tides are shorter than one diurnal cycle.

CONCLUSIONS

The application of a computer based tidal control and data acquisition system has substantially improved convenience, accuracy and repeatability of experimental work on tidal models. These advantages are in addition to the obvious labour saving benefits. There are, however, two areas that require more development or study for further improvement. From a systems point of view it appears more desirable to restructure the software so that all model control and data acquisition programs are made fully compatible with a generalized data acquisition and data analysis system for a hydraulics laboratory. This would eliminate duplication in programming efforts. Secondly, the present feedback control scheme is considered unpractical for tidal profiles extending over more than two or three diurnal cycles. It is now felt the controller can be improved by the inclusion of a simple one-dimensional numerical approximation of the scaled model for the estimation of the dynamic storage at each time step. This study could lead to interesting extensions to two or three boundary models.



