COMPUTER SYSTEMS LABORATORY
WASHINGTON UNIVERSITY
ST. LOUIS, MO. 63110

LINC Document No. 2   July 23, 1963

LINC Control Console

Mary Allen Wilkes

Abstract

A guide to the operation of the classic
LINC console functions.

LINC Control Console

Located on the control console are most of the elements required for
manual control of the computer. The toggle switches, arranged in groups
of threes, present digital information to the computer. The pushbuttons,
levers, and rotary switches initiate computer actions and special modes of
operation. In addition, indicator lights show the state of the major computer
elements.

Register Lights

The register lights display the contents of the Accumulator and various
control registers; they are arranged in groups of threes to facilitate reading
in octal form. A light which is lit corresponds to a flip-flop in the "on" or
"one" state. The rightmost light corresponds to bit 0 of the register.

INSTRUCTION - 12 bits. The Instruction lights display the code number of
the instruction currently being executed by the computer. During the execu-
tion of DSC, MUL, ROR, ROL and SCR, the rightmost four bits of the Instruction
register are used for counting. Otherwise, the Instruction lights change only
when the computer is ready to execute a new instruction.

INSTRUCTION LOCATION - 10 bits. During cycle 0 (the I cycle) of all instructions
withdrawn from the memory for execution, the Instruction Location lights display
the memory location of the current instruction. In later cycles, except for
MTP, XSK, SHD, and SAE, these lights display the location of the instruction
the computer will execute next. In later cycles of MTP the lights display the
location of the second word of the MTP instruction; for XSK, SHD, and SAE, they
display the location of the next instruction in sequence, regardless of whether
that instruction may be skipped or not. An instruction executed manually from

the console with the DO TOG INSTR lever affects the Instruction Location lights only when the instruction itself is JMP.

ACCUMULATOR and L - 13 bits. The Accumulator (12 bits) and the Link bit (marked L) are affected only by executing instructions which require their use. They cannot be disturbed by any console operations except DO TOG INSTR.

MEMORY CONTENTS - 12 bits. These lights display all words withdrawn from or stored in the memory. They also display the multiplicand during the last part of a MUL instruction.

MEMORY ADDRESS - 11 bits. The Memory Address lights display the memory location of any word withdrawn from or stored in the memory. Except for later cycles of MUL, DIS, SAM, OPR, and the shift instructions, these lights display the location of the word in the Memory Contents register.

RELAYS. The six Relay lights display the state of the relay flip-flops. They are set to zero when power is turned ON or OFF. Otherwise they are affected only by the ATR instruction.

RUN Lights

Two lights marked R(Run) and P(Pause) indicate the state of the computer's activity. When the computer is operating under program control, the Run light is normally lit. The Run light also comes on during most pushbutton operations. The Pause light will come on during MTP instructions and when a pause is initiated during OPR instructions. When neither light is lit the computer is STOPPED.

CYCLE Lights

The lights marked I, X, O, and E display the cycle periods of an instruction as it is executed by the computer. The I light corresponds to Cycle 0, or

the instruction cycle, during which the instruction is brought into the Instruction register. Cycle 1, marked X, is the index cycle, so called because all instructions except XSK which index a word in the β registers do so in Cycle 1. O and E, the operation and execution cycles, correspond respectively to Cycles 2 and 3.

Toggle Switches

Three sets of toggle switches are available for presenting information to the computer. A switch which is up is said to be in the "one" state. As with the register lights, the rightmost switch is switch 0. The SENSE SWITCHES (6 toggle switches) can be sensed, one switch at a time, by the SNS instruction. They are used while a program is running to control program branching. The RIGHT and LEFT SWITCHES (12 toggle switches each) can be read into the Accumulator with the RSW and LSW instructions. These switches are also used extensively in conjunction with the pushbuttons and levers as described below.

Pushbuttons, Levers, and Rotary Switches

Control of the computer is provided through the various pushbuttons and levers at the control console. Some execute instructions or monitor stored instructions as they are executed by the computer. Others are used to examine or change the contents of words in the computer memory, and others, such as MARK and CLEAR, change the operating state of the computer altogether.

The pushbuttons labelled AUTO RESTART, ISTOP, XOESTOP, FILL, EXAM, CYCLE BY CYCLE, INSTR BY INSTR, CLEAR, and MARK will light when pushed. The other pushbuttons and the levers do not light. Generally a lighted pushbutton indicates that the computer is operating in the stated mode. Those buttons with no

light initiate single actions; to repeat the action the button or lever must be pressed again.

Most of the pushbuttons and levers are mutually exclusive; operating one of them will generally disable the others. Pushing a button which is illuminated will simply repeat the indicated action. A mode is generally left only by initiating some other console action leading to a new mode. Exceptions to this are described individually below.

The control console is designed so that most actions can be initiated at any time without damaging a running program or a tape transfer. When an action is initiated while the computer is Running (the R light on), the computer waits until a "safe" time (t_1 time of the I Cycle (0) of the next instruction) before changing mode. That is, it will always finish an instruction whose execution is in progress before changing to a new mode. The same is true if an action is initiated when the computer is Stopped in the X, O, or E Cycles (Cycles 1, 2 or 3). Under these circumstances the computer will be set to Run and will proceed to the next "safe" time, t_1 time, of the I Cycle of the next instruction. (The exception to this occurs in STEP actions when CYCLE BY CYCLE is on; see below.) Furthermore, console actions do not affect the Instruction Location register or the Accumulator (unless they are specifically intended to do so, e.g. START 20). The user, therefore, can always resume normal running operation after interrupting a Running or Stopped computer.

The Stop lever is the only means of interrupting the computer if the computer is in the Pause state. If the computer is interrupted while Paused, it will not finish the instruction.

The above remarks about mode changing do not pertain to the AUTO RESTART, ISTOP, and XOESTOP pushbuttons. These take effect independently of the rest of the console, and are recognized without interruption of the computer.

ON. The ON pushbutton supplies power to the computer and initiates certain "presetting" actions which turn control elements to an "off" or "safe" state. Pushing this button when the computer is off will start the central clock and leave the computer in a ready state to begin operations.[1] The Run, Cycle, Instruction, and Relay lights will be cleared, the console pushbuttons cleared, the tape write-gate shut off, and the computer and the tapes left in the STOPPED state. The contents of the memory and the tapes are not affected. Pushing ON when the computer is already on has no effect.

OFF. The OFF pushbutton removes power from the computer. As power disappears, presetting pulses appear temporarily as in turning ON. However, since this presetting is not at present synchronized with other actions, it is advisable to make sure the computer is STOPPED (the RUN lights both out) before pushing OFF. Pushing OFF when the computer is running (R) or paused (P) may destroy a word in the memory or on the tape. Pushing OFF when the computer is already off has no effect. *Be sure to remove tapes before pressing OFF.*

CLEAR. The red CLEAR pushbutton clears the computer memory and does a simple memory read-write test. Pushing this button clears all other console functions and puts the computer in a clear and test mode; the CLEAR light and the R light will come on. The Cycle lights will go out. On alternate passes through the memory the computer writes and reads zeroes, then writes and reads ones, in each memory register. Should the memory test fail, the computer will STOP (RUN lights out). The Memory Address register and the Memory Contents register will display the location and contents of the memory register which failed. If

[1] No warm-up time is necessary except for the scopes, which require about 40 secs.

the computer was writing and reading zeroes at the time of the failure, all

the bits in the Memory Contents register will be zero except the bit(s) which

failed, indicating that the memory has "picked up a one". If the computer

was writing and reading ones, all the bits in the Memory Contents register will

be ones, except the bit(s) which failed, indicating that the memory has "dropped

a one". The computer will stay in the CLEAR mode until some other console action

is initiated. Regardless of whether the computer was on a pass testing for

zeroes or testing for ones, the entire memory is always left with zeroes when

the CLEAR mode is interrupted. ISTOP and XOESTOP are not recognized when the

computer is in the CLEAR mode.

MARK. The red MARK pushbutton is used in conjunction with a special program to

generate LINC tapes. Pushing this button clears all other console functions

except ISTOP and XOESTOP, puts the computer into the MARK TAPE mode, and begins

executing instructions at location 40. Although the computer operates under

program control when generating tapes, the SAE instruction behaves differently

in the MARK mode. Although some console actions may be initiated, they will

disrupt the tape generation timing and may disable the MARK mode itself. There-

fore no other console actions should be initiated while the MARK light is on.

Likewise, the MARK button should not be pushed except when it is expressly

desired to generate a tape. However, unless the computer encounters an MSC 13

instruction, pushing the MARK button will not damage the information on tape.

The MARK button can be turned off by starting some other console function,

or by executing a HLT or MTP instruction.

EXAM. The EXAM pushbutton is used in conjunction with the Left Switches to

examine one memory word. Pushing this button interrupts any operation the

computer might have been carrying out, and clears all other console functions

except ISTOP and XOESTOP. When EXAM is pushed, the EXAM light will come on

and the contents of the word whose address matches the setting of the Left

Switches will appear in the Memory Contents lights. The setting of the Left

Switches will appear in the Memory Address lights. The computer will STOP

(RUN lights out). It will remain in the EXAM mode until some other console

action is specified.

FILL. The FILL pushbutton is used in conjunction with the Left and Right

Switches to fill one memory word from the console. Pushing FILL interrupts

any operation the computer might have been carrying out, and clears all other

console functions except ISTOP and XOESTOP. When the FILL button is pushed,

the FILL light comes on and the word held in the Right Switches is stored in

the memory at the location specified by the Left Switches. The settings of

the Left and Right Switches will appear respectively in the Memory Address

and Memory Contents lights. When the FILL button is released, the light goes

out and the EXAM light comes on. The computer examines the word addressed by

the Left Switches, just as though EXAM had been pushed, and STOPS. The computer

will remain in the EXAM mode until some other console function is specified.

Pushing FILL affects only the memory word addressed by the Left Switches; it

may be used when the computer is Running or Stopped.

STEP EXAM. The STEP EXAM lever interrupts any operation the computer might

have been carrying out, and clears all other console functions except ISTOP

and XOESTOP. It operates like EXAM except that the Left Switches are not read

into the Memory Address register. Instead, STEP EXAM steps the contents of

the Memory Address register by 1, and displays in the Memory Contents register

the word at that location. The EXAM light comes on, and the computer STOPS. It

will remain in the STEP EXAM mode with the EXAM light on until another console action is initiated. STEP EXAM may be used when the computer is Running or Stopped.

FILL STEP. The FILL STEP lever interrupts any operation the computer might have been carrying out, and clears all other console functions except ISTOP and XOESTOP. It operates like FILL except that the Left Switches are not read into the Memory Address register. Instead, when FILL STEP is pressed, the FILL light comes on and the contents of the Right Switches are read into the Memory Contents register and are stored in the memory at the location specified by the Memory Address register. When FILL STEP is released, the computer behaves as in STEP EXAM and Stops. That is, the contents of the Memory Address register are stepped by 1, and the word at that location is displayed in the Memory Contents register. The EXAM light comes on and the computer is left in the STEP EXAM mode. FILL STEP may be used when the computer is Running or Stopped.

Selective Starts

The following console actions interrupt any operation the computer might have been carrying out, and cause it to start executing instructions at the selected location. They clear all other console functions except ISTOP and XOESTOP, and put the computer directly into the Run state. They may be used when the computer is Running or Stopped.

START 20. The computer begins executing instructions starting at location 20.

START 400. The computer begins executing instructions starting at location 400.

START RS. The computer begins executing instructions starting at the location specified by the Right Switches (RS).

RESUME. The computer begins executing instructions starting at the location

presently displayed in the Instruction Location lights. It can therefore be

used to resume normal running at full speed after an interruption.

Selective Stops

The LINC can be made to Stop under specified conditions in the course of

running a program. The following stops are especially useful when trying to

detect program errors. The LINC always stops at t_1 time (see Instruction

Timing Diagrams), regardless of the kind of Stop specified. Any of the following

stops may be specified when the computer is Running or Stopped.

INSTR BY INSTR and CYCLE BY CYCLE. These pushbuttons interrupt any operation

the computer might have been carrying out and clear all other console functions

except ISTOP and XOESTOP. Pushing either button when the computer is Running

will cause it to Stop at the next I Cycle, t_1 time, i.e. at the beginning of

the next instruction. Pushing either button when the computer is Stopped in

the I Cycle has no effect except to clear other console functions. Pushing

either button when the computer is Stopped in any cycle other than the I Cycle

will cause the computer to Run until the next I Cycle, t_1 time and Stop at the

beginning of that instruction. The pushbutton light comes on and the computer

is left ready to execute one instruction, or one cycle of an instruction, every

time the STEP lever is pressed. When operating in either of these modes, the

computer executes stored programmed instructions just as it does when Running

at full speed, except that it Stops at the specified points.

INSTR BY INSTR. When the computer is in this mode, pressing the STEP lever

causes the computer to execute the instruction displayed in the Instruction

lights and Stop at t_1 time in the I Cycle of the next instruction. Every time

the STEP lever is pressed, the computer executes one more instruction and stops. Every time the computer stops, the I light (Cycle 0) will be on, and the Instruction and Instruction Location lights will describe the next instruction to be executed.

CYCLE BY CYCLE. When the computer is in this mode, pressing the STEP lever causes the computer to execute one cycle of the instruction displayed in the Instruction lights, and Stop at t_1 time of the next cycle. Every time the STEP lever is pressed, the computer executes one more instruction cycle and stops. When the computer stops, the Cycle and Instruction lights will describe the stop point. If the instruction being executed has cycles which repeat (e.g. the shift instructions which repeat Cycle 2 until all the shifts are completed), the computer will stop at each t_1 time, each time the cycle repeats.

The computer will not, however, STEP Cycle by Cycle through an MTP or OPR instruction. This is to prevent possible loss of information because of unusual timing conditions. In these cases, the computer will execute the entire instruction and Stop at t_1 time in the I Cycle of the next instruction. It will not, however, leave the Cycle by Cycle mode.

STEP. The STEP lever is used in the INSTR BY INSTR and CYCLE BY CYCLE modes as described above. When the computer is in neither of these modes, pressing STEP has exactly the same effect as pushing the INSTR BY INSTR button. That is, other console functions will be cleared and the computer will Stop at t_1 time of the next I Cycle. The INSTR BY INSTR light will be on.

ISTOP and XOESTOP. These two pushbuttons are used to stop the computer whenever a reference is made to a selected memory location. The user selects the memory

location by setting the Left Switches. The computer will then stop when the Left Switches match the contents of the Memory Address register.

Either button may be pushed when the computer is Running, Paused, or Stopped, although neither will be recognized when the computer is in the CLEAR mode. Neither button changes the state of the computer until the specified stop condition is met. They clear each other and the AUTO RESTART light, but no other console functions. They are themselves cleared only by pressing the STOP lever or the CLEAR pushbutton.

ISTOP. ISTOP will stop the computer at t_1 time when there is a match between the Left Switches and the Memory Address register in the I Cycle. Since in the I Cycle the Memory Address register always holds the location of the instruction, ISTOP is used to stop the computer when it comes to a selected location in the program. In this case the Instruction Location lights and the Memory Address lights will both match the Left Switches when the computer stops. ISTOP is useful for running full speed to a program trouble spot, at which point the user may wish to STEP Instruction by Instruction or Cycle by Cycle, or to EXAMine a register. If RESUME is pressed the computer will continue normal Running until it again finds a match between the Left Switches and the Memory Address register in the I Cycle.

XOESTOP. The XOESTOP pushbutton will stop the computer at t_1 time when there is an address match in the X, O, or E cycles. When the computer stops, the Memory Address lights will match the Left Switches, and the Cycle lights will display the cycle in which the match was found. The XOESTOP is helpful in tracing the use made of a particular memory register. If, for example, an index register is being incorrectly indexed, or an instruction in the program

is being improperly treated as an operand, XOESTOP together with the Left
Switches makes it possible to check every reference the program makes to the
register in question. XOESTOP will not stop the computer when a match is
found during an MTP or OPR instruction.

The STOP Lever

The lever marked STOP should generally be used when other stops (such
as STEP, INSTR BY INSTR) are not effective. This lever not only stops the
computer, but also does certain presetting of computer control elements.
Pushing STOP when the computer is Running will clear all other console
functions and interrupt the computer at the next I Cycle, t_1 time. The
computer will STOP with the cycle lights cleared. The same is true if
STOP is pressed when the computer is Stopped in the X, O, or E Cycles;
pressing STOP will cause the computer to Run, finish the current instruction,
and then STOP at the next I Cycle, t_1 time with the Cycle lights cleared.
Moreover, STOP will interrupt the computer when the computer is Paused,
i.e. in an MTP or OPR instruction, without finishing the instruction,
Since most console actions cannot be carried out when the computer is Paused,
STOP is used to take the computer out of the Pause state and leave it in the
STOP state, a state in which other console actions are effective. Since STOP
interrupts a Paused computer without finishing the instruction, it can also
be used as a "panic" stop when the user does not want the computer to continue
with an MTP or OPR instruction. If, for example, the user observes that the
computer is about to write on the wrong block on the tape, or read a tape
block into the wrong quarter of memory, STOP can be used in the hope that it
will take effect before the transfer takes place.

Pressing STOP clears not only the RUN and CYCLE lights, but also the Memory Contents lights, as well as any console function including ISTOP and XOESTOP. It also turns off the memory flip-flop (MEMFF), the tape write gate (WGFF), and stops any tape motion.

The DO TOG INSTR Lever

DO TOG INSTR. The DO lever is used with the Left and Right Switches to execute instructions manually at the console. Executing instructions at the console should not be confused with the sequential execution of stored programmed instructions which the computer does, for example, when one of the selective starts is used. The latter requires that instructions be stored in the computer memory; however, when instructions are executed at the console with the DO TOG INSTR lever, the computer reads the instruction from the Left and Right toggle Switches. Pressing the DO TOG INSTR lever clears all other console functions except ISTOP and XOESTOP, and interrupts any action the computer might have been carrying out. The computer executes one instruction and STOPS. The instruction must be set in the Left Switches. The Right Switches are used to hold the second word of double register instructions; they are ignored during the execution of single word instructions. When the DO TOG INSTR lever is pressed, the contents of the Left Switches replace the contents of the Instruction and Memory Contents registers (see Instruction Timing Diagrams, Cycle 0). The Instruction is then executed exactly as though it had come from the memory. The Instruction Location register, however, is never indexed under these circumstances; therefore instructions such as STA i with $\beta = 0$, or SKP, have essentially no effect when executed in this way. The Instruction Location register is changed by Do Tog Instr only when the

instruction in the Left Switches is a JMP X; the value X(the right 10 bits
of the Left Switches) will replace the contents of the Instruction Location
register.

When the computer stops after DO TOG INSTR is used, the Memory Address
lights will be cleared, and the Memory Contents lights will display the last
operand read from or into the memory during the instruction. If the memory
is not used, these lights will be cleared. The Instruction lights will dis-
play the instruction just executed, i.e. they will match the Left Switches.
The Accumulator will have been changed only if used by the instruction, and
the Instruction Location lights will be unchanged (unless the instruction
is JMP). Normally, the Cycle lights will display the last cycle of the
instruction. If the instruction is MTP, however, the Cycle lights will
be left set to the I Cycle. Generally, a setting of the X, O, or E Cycles
as indicated in the Cycle lights shows that the current instruction has
not been finished. After DO TOG INSTR is used, however, the Cycle lights
display the last cycle executed. The DO TOG INSTR lever may be pressed
when the computer is Running or Stopped.

Slow Speed Operations

AUTO RESTART and DELAY. By means of these controls, the LINC can be made
to run at variable speeds while it is executing stored programmed instructions,
or it can be made to repeat certain console functions automatically. The
AUTO RESTART pushbutton is always used following some other console action
to restart the computer automatically whenever it stops. This generally has
the effect of repeating the console function most recently executed. AUTO
RESTART will be recognized any time it is pushed, except when the computer

is stopped in the I Cycle of a HLT instruction. It in no way interrupts a Running or Paused computer, nor does it clear any console functions which may be active. It is itself cleared, however, by any other console action, or by executing a HLT instruction. Therefore, to use AUTO RESTART, the computer must first be in the desired mode of operation before pushing the AUTO RESTART button.

The black rotary switch marked DELAY determines the length of time before restart: the lower part of the switch has 4 discrete positions; the upper part is continuous. Together they provide a total range from a few microseconds to 0.9 sec. Changing the setting on the DELAY switch when AUTO RESTART is not lit has no effect.

When AUTO RESTART is pushed after EXAM, or after FILL (which reverts to EXAM), the computer reexamines the register specified by the Left Switches every time the AUTO RESTART DELAY period is over. The user can change the setting of the Left Switches and examine different registers without pushing EXAM again. When used after STEP-EXAM, or after FILL-STEP, (which reverts to STEP-EXAM), the computer will continue stepping the Memory Address register and examining sequentially the contents of the memory. With CLEAR, the computer will restart automatically every time a memory failure causes it to Stop.

When the computer is in CYCLE BY CYCLE or INSTR BY INSTR, AUTO RESTART effectively replaces the STEP lever (without clearing AUTO RESTART), restarting the computer after every stop at t_1 time when the DELAY period is over. With ISTOP or XOESTOP, AUTO RESTART effectively replaces the RESUME lever (without clearing AUTO RESTART). These applications of AUTO RESTART are often useful in monitoring a program.

After a DO TOG INSTR action, AUTO RESTART will usually cause the computer to repeat the last cycle of the instruction, sometimes with interesting effects. After STOP, AUTO RESTART will clear the Memory Address register and examine register 0 in the Memory Contents register.

The Audio Control

The black rotary switch labeled AUDIO is used for aural monitoring of a Running or Paused computer. Like the Delay switch, its lower part has 2 discrete positions and its upper part is continuous. The gong which rings at a HLT instruction or a CLEAR failure is active only when the lower switch is in position 1. The Audio control in no way interacts with the rest of the control console. ∧ Connected to bit 1 (not 0) of Mem. Addr. Reg.

Interaction of Pushbuttons and Levers

Some console actions can be made to work simultaneously with other console actions, that is, without clearing one another. These are, namely, STEP, CYCLE BY CYCLE, or INSTR BY INSTR which can be held active during START 20, START 400, START RS, or DO TOG INSTR. This, of course, makes it possible to start a program in the Cycle by Cycle or Instruction by Instruction mode, or to observe a Do Toggle Instruction action cycle by cycle.

To start a program (START 20, START 400, or START RS) in one of the STEP modes, _first_ press the STEP lever. Next, _before_ releasing the STEP lever, push the desired selective start button. The INSTR BY INSTR light will come on and the Instruction Location lights will change to the new starting address. Release the STEP lever and the start pushbutton. The computer will indicate that it is Stopped in the I Cycle of the instruction at the starting location, in the INSTR BY INSTR mode. The user may now STEP, one instruction at a time, or he may now push CYCLE BY CYCLE, and then STEP one cycle at a time.

The same procedure may be used with the DO TOG INSTR lever. With this lever, however, the user may push either STEP, CYCLE BY CYCLE, or INSTR BY INSTR, before pressing DO TOG INSTR. Again, the first button (or lever) is not released until the DO TOG INSTR lever has been pressed. After both have been released the computer will indicate that it is Stopped in the I Cycle of the toggle instruction. Either the INSTR BY INSTR or CYCLE BY CYCLE light will be on. The user may now STEP through the instruction.

If the toggle instruction is executed CYCLE BY CYCLE, the computer will stop at t_1 time at the beginning of each cycle (except MTP or OPR). At the end of the instruction (after the last cycle has been executed) the computer will bring the next instruction, indicated by the Instruction Location register, into the Instruction and Memory Contents registers, and Stop at t_1 time of the I Cycle of that instruction. It will not stop at the end of the toggle instruction as it does when the DO TOG INSTR lever alone is pressed; it STEPS from the toggle instruction into the next memory instruction. This is also true when the toggle instruction is executed in the INSTR BY INSTR mode.