3. As a result of a memory read operation, the instruction is loaded into the registe MDR.
4. The contents of the MDR are loaded into the register IR.

6.3.2. Execute Cycle

This is the part of the cycle when data processing actually takes place. The instruction i carried out upon the data (executed). The result of this processing is stored in yet anothe register. Once the execute stage is complete, the CPU sets itself up to begin another cycle onc more.

Small Concept

Execute cycle includes reads contents of register, execute instruction and store results back to register.

Let's take an example of instruction

Add R1, R2, R3

The above instruction adds the contents of source registers R1 and R2, and stores th results in destination register R3. This addition can be executed as follows:

1. The registers R3, R1, R2, are extracted from the IR.
2. The contents of R1 and R2 are passed to the ALU for addition.
3. The output of the ALU is transferred to R3.

6.4. CONTROL UNIT

To execute an instruction, the control unit of the CPU must generate the required contro signal in the proper sequence. As for example, during the fetch phase, CPU has to generat PCout signal along with other required signal in the first clock pulse. In the second clock puls CPU has to generate PCin signal along with other required signals. So, during fetch phase, the proper sequence for generating the signal to retrieve from and store to PC is PC_{out} and PC_{in}

To generate the control signal in proper sequence, a wide variety of techniques exist. Most of these techniques, however, fall into one of the two categories,

1. Hardwired Control Unit
2. Microprogrammed Control Unit.

6.4.1. Hardwired Control Unit

In this hardwired control techniques, the control signals are generated by means of hardwired circuit. The main objective of control unit is to generate the control signal in proper sequence.

Small Concept

Hardwired control unit is designed by hardware components such as logic gates, flip-flops, decoders or other digital circuits.

Consider the sequence of control signal required to execute the ADD instruction that is explained in previous lecture. It is obvious that eight non-overlapping time slots are required for proper execution of the instruction represented by this sequence.

Each time slot must be at least long enough for the function specified in the corresponding step to be completed. Since, the control unit is implemented by hardwire device and every device is having a propagation delay, due to which it requires some time to get the stable output signal at the output port after giving the input signal. So, to find out the time slot is a complicated design task.

For the moment, for simplicity, let us assume that all slots are equal in time duration. Therefore the required controller may be implemented based upon the use of a counter driven by a clock.

Each state, or count, of this counter corresponds to one of the steps of the control sequence of the instructions of the CPU.

Basic Features of Control Unit :

- The control logic is implemented with gates, Flip-Flops, Decoders, and other Digital Circuits
- Its provides fast operation due to direct connection.
- Big disadvantage is the change of wiring if the design has to be modified.

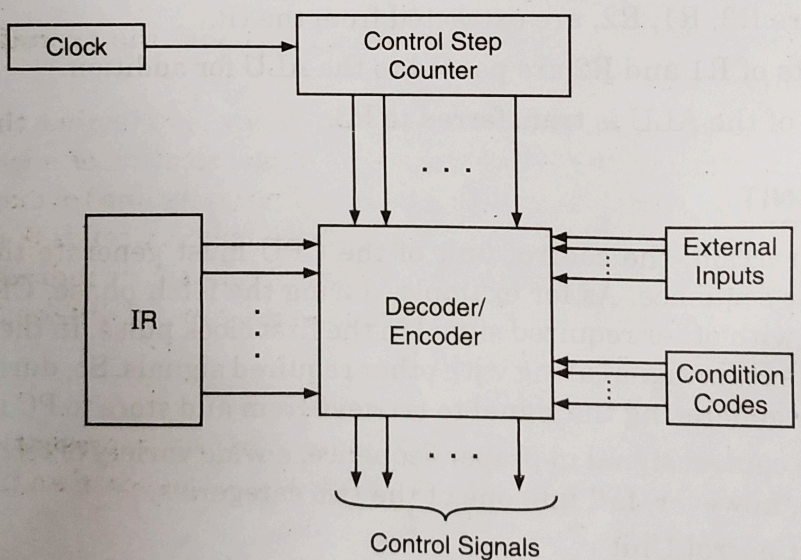

Fig. 6.6. Organization of control unit

The structure of control unit can be represented in a simplified view by putting it in block diagram. The detailed hardware involved may be explored step by step. The simplified view of the control unit is given in the Fig. 6.6.

The decoder/encoder block is simply a combinational circuit that generates the required control outputs depending on the state of all its input.

The decoder part of decoder/encoder part provide a separate signal line for each control step, or time slot in the control sequence. Similarly, the output of the instructor decoder consist of a separate line for each machine instruction loaded in the IR, one of the output line INS1 to INSm is set to 1 and all other lines are set to 0.

6.4.2. Microprogrammed Control Unit

In hardwired control, we saw how all the control signals required inside the CPU. There is an alternative approach by which the control signals required inside the CPU can be generated. This alternative approach is known as microprogrammed control unit.

In microprogrammed control unit, the logic of the control unit is specified by a microprogram. A microprogram consists of a sequence of instructions in a microprogramming language. These are instructions that specify microoperations.

Small Concept

Micro-programmed control unit designed by software programs instead of hardware components using micro-instruction.

A microprogrammed control unit is a relatively simple logic circuit that is capable of

1. sequencing through microinstructions and
2. generating control signals to execute each microinstruction.

The concept of microprogram is similar to computer program. In computer program the complete instructions of the program is stored in main memory and during execution it fetches the instructions from main memory one after another. The sequence of instruction fetch is controlled by program counter (PC) .

Microprogram are stored in microprogram memory and the execution is controlled by microprogram counter (μPC).

Microprogram consists of microinstructions which are nothing but the strings of 0's and 1's. In a particular instance, we read the contents of one location of microprogram memory, which is nothing but a microinstruction. Each output line (data line) of microprogram memory corresponds to one control signal. If the contents of the memory cell is 0, it indicates that the signal is not generated and if the contents of memory cell is 1, it indicates to generate that control signal at that instant of time. First let discuss the some of different terminologies that are related to microprogrammed control unit.

Control Word (CW)

Control word is defined as a word whose individual bits represent the various control signal. Therefore each of the control steps in the control sequence of an instruction defines a unique combination of 0s and 1s in the CW.

Microinstructions & Microprogram

A sequence of control words (CWs) corresponding to the control sequence of a machine instruction constitutes the microprogram for that instruction. The individual control words in this microprogram are referred to as microinstructions.

Microprogram Memory

The microprograms corresponding to the instruction set of a computer are stored in a special memory which will be referred to as the microprogram memory. The control words related to an instructions are stored in microprogram memory also referred as control memory.

Microprogram Counter (μPC)

The control unit can generate the control signals for any instruction by sequentially reading the CWs of the corresponding microprogram from the microprogram memory. To read the control word sequentially from the microprogram memory a microprogram counter (μPC) is needed. The basic organization of a microprogrammed control unit is shown in the Fig. 6.7.

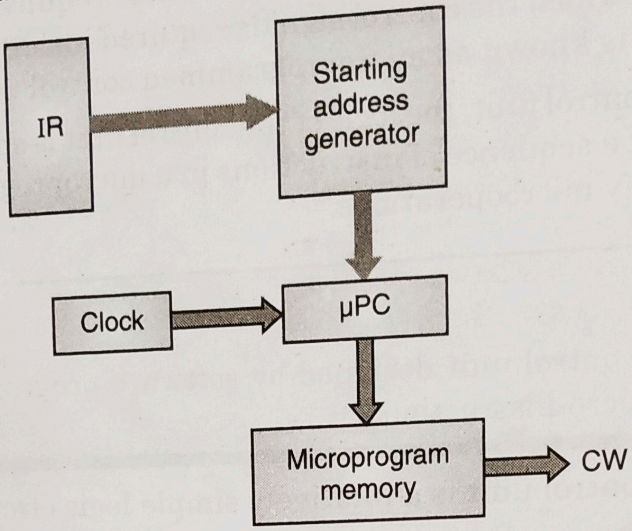

Fig. 6.7. Basic organization of a microprogrammed control Unit

The "starting address generator" block is responsible for loading the starting address of the microprogram into the PC every time a new instruction is loaded in the IR. The μPC is then automatically incremented by the clock, and it reads the successive microinstruction from memory.

Each microinstruction basically provides the required control signal at that time step. The microprogram counter ensures that the control signal will be delivered to the various parts of the CPU in correct sequence.

We have some instructions whose execution depends on the status of condition codes and status flag, as for example, the branch instruction. During branch instruction execution, it is required to take the decision between the alternative action. To handle such type of instructions with microprogrammed control, the design of control unit is based on the concept of conditional branching in the microprogram. For that it is required to include some conditional branch microinstructions.

Small Concept

- **Micro-operations** are the arithmetic logic operations on the registers.
- **Micro instruction** is the set of micro-operations.
- **Micro program** is the set of micro-instructions.

In conditional microinstructions, it is required to specify the address of the microprogram memory to which the control must direct. It is known as branch address. Apart from branch address, these microinstructions can specify which of the states flags, condition codes, or possibly, bits of the instruction register should be checked as a condition for branching to take place.

To support microprogram branching, the organization of control unit should be modified to accommodate the branching decision. To generate the branch address, it is required to know the status of the condition codes and status flag. To generate the starting address, we need the instruction which is present in IR. But for branch address generation we have to check the content of condition codes and status flag.

The organization of control unit to enable conditional branching in the microprogram is shown in the Fig. 6.8.

In the previous discussion, to design a micro programmed control unit, we have to do the following:

- For each instruction of the CPU, we have to write a microprogram to generate the control signal. The microprograms are stored in microprogram memory (control store). The starting address of each microprogram are known to the designer
- Each microprogram is the sequence of microintructions. And these microinstructions are executed in sequence. The execution sequence is maintained by microprogram counter.
- Each microinstructions are nothing but the combination of 0's and 1's which is known as control word. Each position of control word specifies a particular control signal. 0 on the control word means that a low signal value is generated for that control signal at that particular instant of time, similarly 1 indicates a high signal.
- Since each machine instruction is executed by a corresponding micro routine, it follows that a starting address for the micro routine must be specified as a function of the contents of the instruction register (IR).
- To incorporate the branching instruction, i.e., the branching within the microprogram, a branch address generator unit must be included. Both unconditional and conditional branching can be achieved with the help of microprogram. To incorporate the conditional branching instruction, it is required to check the contents of condition code and status flag.

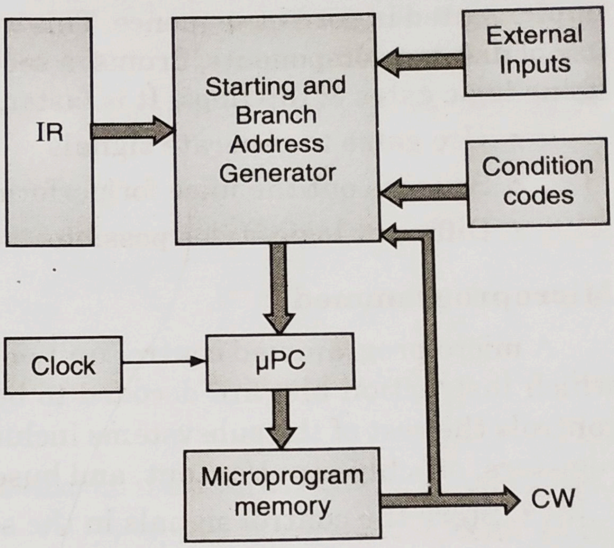

Fig. 6.8. Organization of microprogrammed control with conditional branching

Advantages and Disadvantages

The principal advantage of the use of microprogramming to implement a control unit is that it simplifies the design of the control unit. Thus, it is both cheaper and less error prone to implement. A hardwired control unit must contain complex logic for sequencing through the many micro-operations of the instruction cycle. On the other hand, the decoders and sequencing logic unit of a microprogrammed control unit are very simple pieces of logic.

Small Concept

Micro program reduce the hardware complexity as well as size of hardware requirements.

The principal disadvantage of a microprogrammed unit is that it will be somewhat slower than a hardwired unit of comparable technology. Despite this, microprogramming is the dominant technique for implementing control units in pure CISC architectures, due to its ease of implementation. RISC processors, with their simpler instruction format, typically use hardwired control units.

6.4.3. Hardwired Vs Microprogrammed

Hardwired

A hardwired control unit has a processor that generates signals or instructions to be implemented in correct sequence. This was the older method of control that works through the use of distinct components, drums, a sequential circuit design, or flip chips. It is implemented using logic gates & flip flops. It is faster, less flexible & limited in complexity

- Use gates to generate signals
- Squeeze out the juice for performance
- Different logic styles possible

Microprogrammed

A micro programmed control unit on the other hand makes use of a micro sequencer from which instruction bits are decoded to be implemented. It acts as the device supervisor that controls the rest of the subsystems including arithmetic and logic units, registers, instruction registers, off-chip input/output, and buses.

- Store the control signals in the sequence
- Just read from the memory every clock cycle
- It is slower, more flexible & greater complexity

POINTS TO REMEMBER

- This chapter introduced the basic functions of processor. The CPU (Central Processing Unit) or Processor is responsible for fetching, decoding and executing an instruction.
- A CPU fetches program instructions from RAM (input), interprets and processes it (execution) and then sends back the computed results so that the relevant components can carry out the instructions.
- There are four important functions of CPU,
  - (i) **Fetch:** the process to read the instruction from memory
  - (ii) **Decode:** the process to interpret the instruction
  - (iii) **Execute:** the process to perform the required arithmetic and logical operation.
  - (iv) **Write back:** the process to transfer the result of an execution of instruction.
- There are three basic components of the CPU:
  - (i) Arithmetic Logic Unit
  - (ii) Control Unit
  - (iii) Register Set (Memory Unit)
- ALU executes all arithmetic and logical operations calculations such as addition, subtraction, multiplication and division as well as comparisons.
- The Control Unit uses electrical signals to instruct the whole computer system for carrying out or executing, already stored program instructions.
- Registers are temporary storage areas which are responsible for holding the data to be processed. They store the instructions and data in a processor.
- General-purpose registers can be ... variety of functions by the ...