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| **实验四、微程序控制器实验**   1. **实验任务及目的**   实验目的：   * + - 1. 掌握微程序控制器的原理；       2. 掌握TEC-8模型计算机中微程序控制器的实现方法，尤其是微地址转移逻辑的实现方法；       3. 理解条件转移对计算机的重要性   实验任务：  熟悉微程序流程图和微程序指令系统  跟踪控制台操作写寄存器、写存储器、读存储器、读寄存器、的执行过程；  跟踪指令的执行过程  执行ADD、LD、ST指令   1. **实验电路分析**     该电路由上面的CM组组成控制存储器、REG6微地址寄存器和下方的微地址转移逻辑组成。微地址转移逻辑通过判别字段（P0~P4）和外部条件决定下一条微指令的地址。   * + - 1. 默认情况：如果p=00000，则直接采用NμA5~NμA0​​作为下一条微指令的地址       2. 条件转移：  1. P0=1时，就根据SW的值修改下一条指令的地址，根据电路图，我们可以知道此时将SWC-SWA替换下址的次低三位。 2. P1=1时，根据指令操作码IR7-IR4修改下一条指令的地址，此时将IR7-IR4替换下址的低4位 3. 当P2=1时。根据进位标志C修改下一条指令的地址，此时若进位标志为1时，将C替代下址的最低位 4. 当P3=1时，根据零标志位修改下一条指令的地址，此时若零标志位为1，则用其替换下址的最低位 5. 当P4=1时，根据中断信号INT修改下一条指令的地址，此时若INT=1，则使用INT替换下址的第五位 6. **微程序流程图分析**     初始状态处于00H地址中，若此时p0有效，则根据SW的值来修改下址，此时可以进入写/读寄存器/存储器以及取值模式。在存储器的两个循环中，单击CLR即可跳出，并回到初态。如果进入取值模式，取出指令后，p1有效，根据IR7-IR4跳转到各条微指令地址并执行。如果执行的是条件跳转指令JC和JZ，则分别是p2,p3有效，根据C/Z确定下址的地址。微指令执行完毕后p4有效，并根据INT的值确定下一条地址是01H还是11H。   1. **实验过程及结果**  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | **写寄存器（向R0-R3分别存入4个数）** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | **序号** | **操作** | | | | | | | **操作的数据** | | | | **操作目的** | | | | **操作结果** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | **控制信号（有效的信号）** | | | | | **μA** | | | | | **NμA** | | | | | | **D7-D0** | | | | **A7-A0** | | | | | **B7-B0** | | | | 1 | CLR | | | | | | | 无 | | | | 复位 | | | | SEL3-SEL0=0011 P0=1 | | | | | 00H | | | | | 01H | | | | | |  | | | |  | | | | |  | | | | 2 | SW=100 QD | | | | | | | 无 | | | | 进入写寄存器模式 | | | | SBUS=1 SEL3-SEL0=0001 SELCTL=1 DRW=1 STOP=1 | | | | | 09H | | | | | 08H | | | | | |  | | | |  | | | | |  | | | | 3 | SD7-SD0=00H QD | | | | | | | 00H | | | | 将00H写入R0 并跳转到下一条微指令 | | | | SBUS=1 SEL3-SEL0=0100 SELCTL=1 DRW=1 STOP=1 | | | | | 08H | | | | | 0AH | | | | | | 00H | | | |  | | | | | 00H | | | | 4 | SD7-SD0=01H QD | | | | | | | 01H | | | | 将01H写入R1 并跳转到下一条微指令 | | | | SBUS=1 SEL3-SEL0=1001 SELCTL=1 DRW=1 STOP=1 | | | | | 0AH | | | | | 0CH | | | | | | 01H | | | |  | | | | | 01H | | | | 5 | SD7-SD0=02H QD | | | | | | | 02H | | | | 将02H写入R2 并跳转到下一条微指令 | | | | SBUS=1 SEL3-SEL0=1110 SELCTL=1 DRW=1 STOP=1 | | | | | 0CH | | | | | 00H | | | | | | 02H | | | |  | | | | | 02H | | | | 6 | SD7-SD0=03H QD | | | | | | | 03H | | | | 将03H写入R3 并跳转到下一条微指令 | | | | SEL3-SEL0=0011 P0=1 | | | | | 00H | | | | | 01H | | | | | | 03H | | | | 00H | | | | | 03H | | | | **写存储器（向存储器的00H,01H,02H,03H地址分别存入4个指令或数据）** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  | | | | | **序号** | | | | **操作** | | | **操作的数据** | | | | **操作目的** | | | | **操作结果** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | **控制信号（有效的信号）** | | | | | **μA** | | | | **NμA** | | | | | **D7-D0** | | | | | | **A7-A0** | | **B7-B0** | | | **AR7-AR0** | | | | | 1 | | | | CLR | | | 无 | | | | 复位 | | | | SEL3-SEL0=0011 P0=1 | | | | | 00H | | | | 01H | | | | |  | | | | | |  | |  | | |  | | | | | 2 | | | | SW=010 QD | | | 无 | | | | 进入写存储器模式 | | | | SBUS=1 LAR=1 STOP=1 SELCTL=1 | | | | | 03H | | | | 02H | | | | |  | | | | | |  | |  | | |  | | | | | 3 | | | | SD7-SD0=00H QD | | | 00H | | | | 向地址寄存器中打入初地址00H | | | | SBUS=1 MEMW=1 ARINC=1 STOP=1 SELCTL=1 | | | | | 02H | | | | 02H | | | | | 00H | | | | | |  | |  | | | 00H | | | | | 4 | | | | SD7-SD0=00H QD | | | 00H | | | | 向地址00H中写入 00H | | | | SBUS=1 MEMW=1 ARINC=1 STOP=1 SELCTL=1 | | | | | 02H | | | | 02H | | | | | 00H | | | | | |  | |  | | | 01H | | | | | 5 | | | | SD7-SD0=01H QD | | | 01H | | | | 向地址01H中写入 01H | | | | SBUS=1 MEMW=1 ARINC=1 STOP=1 SELCTL=1 | | | | | 2H | | | | 2H | | | | | 01H | | | | | |  | |  | | | 02H | | | | | 6 | | | | SD7-SD0=02H QD | | | 02H | | | | 向地址02H中写入 02H | | | | SBUS=1 MEMW=1 ARINC=1 STOP=1 SELCTL=1 | | | | | 2H | | | | 2H | | | | | 02H | | | | | |  | |  | | | 03H | | | | | 7 | | | | SD7-SD0=03H QD | | | 03H | | | | 向地址03H中写入 03H | | | | SBUS=1 MEMW=1 ARINC=1 STOP=1 SELCTL=1 | | | | | 2H | | | | 2H | | | | | 03H | | | | | |  | |  | | | 04H | | | | | 8 | | | | CLR | | | 无 | | | | 跳出写存储器循环 | | | | SEL3-SEL0=0011 P0=1 | | | | | 00H | | | | 01H | | | | |  | | | | | |  | |  | | |  | | | | | 9 | | | |  | | |  | | | |  | | | |  | | | | |  | | | |  | | | | |  | | | | | |  | |  | | |  | | | | | 10 | | | |  | | |  | | | |  | | | |  | | | | |  | | | |  | | | | |  | | | | | |  | |  | | |  | | | | | 11 | | | |  | | |  | | | |  | | | |  | | | | |  | | | |  | | | | |  | | | | | |  | |  | | |  | | | | | **指令执行-ADD** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  | | | | | |  | | | |  | | **序号** | | | **操作** | | **操作的数据** | | | | | **操作目的** | | | | **操作结果** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | **控制信号** | | | **μA** | **NμA** | | | | | **D7-D0** | | | | **A7-A0** | | | **B7-B0** | | | **PC7-PC0** | | | | | | **INS7-INS0** | | | | **IR7-IR0** | | 1 | | | CLR | | 无 | | | | | 复位 | | | | SEL3-SEL0=0011 P0=1 | | | 00H | 01H | | | | |  | | | |  | | |  | | |  | | | | | |  | | | |  | | 2 | | | SW=000 QD | | 无 | | | | | 进入取指模式 | | | | LIR=1 PCINC=1 P1=1 | | | 01H | 20H | | | | |  | | | |  | | |  | | | 00H | | | | | | 00H | | | | 00H | | 3 | | | IR7-IR4=0001 QD | | 0001 | | | | | 执行ADD指令 | | | | S=1001 CIN=1 ABUS=1 DRW=1 LDZ=1 LDC=1 P4=1 | | | 21H | 01H | | | | | 00H | | | | 00H | | | 00H | | | 01H | | | | | | 01H | | | | 00H | | 4 | | |  | |  | | | | |  | | | |  | | |  |  | | | | |  | | | |  | | |  | | |  | | | | | |  | | | |  | | 5 | | |  | |  | | | | |  | | | |  | | |  |  | | | | |  | | | |  | | |  | | |  | | | | | |  | | | |  | | 6 | | |  | |  | | | | |  | | | |  | | |  |  | | | | |  | | | |  | | |  | | |  | | | | | |  | | | |  | | 7 | | |  | |  | | | | |  | | | |  | | |  |  | | | | |  | | | |  | | |  | | |  | | | | | |  | | | |  | | 8 | | |  | |  | | | | |  | | | |  | | |  |  | | | | |  | | | |  | | |  | | |  | | | | | |  | | | |  | | **指令执行-LD** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  | | | |  | | | |  | | | **序号** | | **操作** | | | | **操作的数据** | | | **操作目的** | | | | **操作结果** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | **控制信号（有效的信号）** | | | | | | **μA** | | | **NμA** | | | **D7-D0** | | | **A7-A0** | | | **B7-B0** | | | **PC7-PC0** | | | | **INS7-INS0** | | | | **IR7-IR0** | | | 1 | | CLR | | | | 无 | | | 复位 | | | | SEL3-SEL0=0011 P0=1 | | | | | | 00H | | | 01H | | |  | | |  | | |  | | |  | | | |  | | | |  | | | 2 | | SW=000 QD | | | | 无 | | | 进入取指模式 | | | | LIR=1 PCINC=1 P1=1 | | | | | | 01H | | | 20H | | |  | | |  | | |  | | | 00H | | | | 00H | | | | 00H | | | 3 | | IR7-IR4=0101 QD | | | | 0101 | | | 执行LD指令 | | | | M=1 S=1010 ABUS=1 LAR=1 | | | | | | 25H | | | 0EH | | | 00H | | | 00H | | | 00H | | | 01H | | | | 01H | | | | 00H | | | 4 | | QD | | | | 无 | | | 执行LD指令 | | | | MBUS=1 DRW=1 P4=1 | | | | | | 0EH | | | 01H | | | 00H | | |  | | |  | | | 01H | | | | 01H | | | | 00H | |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | **指令执行-ST** | | | | | | | | | |  |  |  | | **序号** | **操作** | **操作的数据** | **操作目的** | **操作结果** | | | | | | | | | | **控制信号（有效的信号）** | **μA** | **NμA** | **D7-D0** | **A7-A0** | **B7-B0** | **PC7-PC0** | **INS7-INS0** | **IR7-IR0** | | 1 | CLR | 无 | 复位 | SEL3-SEL0=0011 P0=1 | 00H | 01H |  |  |  |  |  |  | | 2 | SW=000 QD | 无 | 进入取指模式 | LIR=1 PCINC=1 P1=1 | 01H | 20H |  |  |  | 00H | 00H | 00H | | 3 | IR7-IR4=0110 QD | 0110 | 执行ST指令 | M=1 S=1111 ABUS=1 LAR=1 | 26H | 10H | 00H | 00H | 00H | 01H | 01H | 00H | | 4 | QD |  | 执行ST指令 | M=1 S=1010 ABUS=1 MEMW=1 P4=1 | 10H | 01H | 00H | 00H | 00H | 01H | 01H | 00H |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | **读寄存器（从R0-R3中分别读出它们存储的数据）** | | | | | | | | | | | **序号** | **操作** | **操作的数据** | **操作目的** | **操作结果** | | | | | | | **控制信号（有效的信号）** | **μA** | **NμA** | **D7-D0** | **A7-A0** | **B7-B0** | | 1 | CLR | 无 | 复位 | SEL3-SEL0=0011 P0=1 | 00H | 01H |  |  |  | | 2 | SW=011 QD | 011 | 进入读寄存器模式 | SEL3-SEL0=0001 SELCTL=1 STOP=1 | 07H | 06H |  | 00H | 01H | | 3 | QD | 无 | 继续执行指令 | SEL3-SEL0=1011 SELCTL=1 STOP=2 | 06H | 00H |  | 02H | 03H |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | **读存储器（从存储器的00H,01H,02H,03地址分别读出其中存储的指令或数据）** | | | | | | | | | |  | | **序号** | **操作** | **操作的数据** | **操作目的** | **操作结果** | | | | | | | | **控制信号（有效的信号）** | **μA** | **NμA** | **D7-D0** | **A7-A0** | **B7-B0** | **AR7-AR0** | | 1 | CLR | 无 | 复位 | SEL3-SEL0=0011 P0=1 | 00H | 01H |  |  |  |  | | 2 | SW=001 QD | 无 | 进入读存储器模式 | SBUS=1 LAR=1 STOP=1 SELCTL=1 | 05H | 04H |  |  |  |  | | 3 | SD7-SD0=00H QD | 00H | 设置初地址 | MBUS=1 ARINC=1 STOP=1 SELCTL=1 | 04H | 04H | 00H QD后变为00H |  |  | 00H | | 4 | QD | 无 |  | MBUS=1 ARINC=1 STOP=1 SELCTL=1 | 04H | 04H | 01H |  |  | 01H | | 5 | QD | 无 |  | MBUS=1 ARINC=1 STOP=1 SELCTL=1 | 04H | 04H | 02H |  |  | 02H | | 6 | QD | 无 |  | MBUS=1 ARINC=1 STOP=1 SELCTL=1 | 04H | 04H | 03H |  |  | 03H | | 7 | CLR | 无 | 跳出循环 | SEL3-SEL0=0011 P0=1 |  |  |  |  |  |  |  1. **实验收获及体会**   通过本次实验，我深入理解了微程序控制器的工作原理，掌握了微地址转移逻辑的实现方法，特别是判别位（P0-P4）与外部条件（如SW开关、IR操作码、C/Z标志、INT中断）协同控制程序流程的机制。在跟踪ADD、LD、ST指令执行过程中，我直观体会到控制信号与时序配合的重要性，并通过实际操作熟悉了TEC-8模型计算机的数据通路设计。实验还让我认识到微程序控制的灵活性优势，以及条件转移对实现程序分支的关键作用，这些认知为后续学习计算机体系结构奠定了实践基础。  **实验五、CPU组成与机器指令的执行**   1. **实验任务及目的**   实验目的：   * + - 1. 用微程序控制器控制数据通路，将相应的信号线连接，构成一台能够运行测试程序的CPU       2. 执行一个简单的程序，掌握机器指令与微指令的关系       3. 理解计算机如何取出指令、如何执行指令、如何在一条指令执行结束之后自动取出下一条指令并执行，从而牢固建立计算机整机概念。   实验任务：   1. 完成对给定程序的手工汇编； 2. 通过简单的连线构成能够运行程序的TEC-8模型计算机； 3. 将程序写入存储器，给寄存器R2、R3赋初值； 4. 跟踪执行程序，用单拍方式运行一遍，用连续方式运行一遍，详细记录实验过程及结果； 5. 用实验台操作检查程序运行结果。 6. **程序的手工汇编结果**      1. **实验过程及结果**  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | 指令 | μA | NμA | P | INS | PC | AR | IR | A | B | D | |  | 000001 | 100000 | 00010 | 01010011 | 00H | 00H | 00000000 | 00H | 00H | 00H | | LD R0,[R3] | 100101 | 001110 | 00000 | 01010011 | 01H | 00H | 01010011 | 00H | 0FH | 0FH | |  | 001110 | 000001 | 10000 | 01001100 | 01H | 0FH | 01010011 | 00H | 0FH | 85H | |  | 000001 | 100000 | 00010 | 01001100 | 01H | 0FH | 01010011 | 85H | 0FH | 00H | | INC R3 | 100100 | 000001 | 10000 | 01010111 | 02H | 0FH | 01001100 | 0FH | 85H | 01H | |  | 000001 | 100000 | 00010 | 01010111 | 02H | 0FH | 01001100 | 10H | 85H | 00H | | LD R1,[R3] | 100011 | 001110 | 00000 | 00100001 | 03H | 0FH | 01010111 | 00H | 10H | 10H | |  | 001110 | 000001 | 10000 | 00100001 | 03H | 10H | 01010111 | 00H | 10H | 23H | |  | 000001 | 100000 | 00010 | 00100001 | 03H | 10H | 01010111 | 23H | 10H | 00H | | SUB R0,R1 | 100010 | 000001 | 10000 | 10000110 | 04H | 10H | 00100001 | 85H | 23H | 62H | |  | 000001 | 100000 | 00010 | 10000110 | 04H | 10H | 00100001 | 62H | 23H | 00H | | JZ 0BH | 101000 | 100010 | 01000 | 01101000 | 05H | 10H | 10000110 | 23H | 12H | 00H | |  | 010010 | 000001 | 10000 | 01101000 | 05H | 10H | 10000110 | 23H | 12H | 00H | |  | 000001 | 100000 | 00010 | 01101000 | 05H | 10H | 10000110 | 23H | 12H | 00H | | ST R0,[R2] | 100110 | 010000 | 00000 | 01001100 | 06H | 10H | 01101000 | 12H | 23H | 12H | |  | 010000 | 000001 | 10000 | 01001100 | 06H | 12H | 01101000 | 12H | 62H | 62H | |  | 000001 | 100000 | 00010 | 01001100 | 06H | 12H | 01101000 | 12H | 62H | 00H | | INC R3 | 100100 | 000001 | 10000 | 01010011 | 07H | 12H | 01001100 | 10H | 62H | 11H | |  | 000001 | 100000 | 00010 | 01010011 | 07H | 12H | 01001100 | 11H | 62H | 00H | | LD R0,[R3] | 100101 | 001110 | 00000 | 00010001 | 08H | 12H | 01010011 | 62H | 11H | 11H | |  | 001110 | 000001 | 10000 | 00010001 | 08H | 11H | 01010011 | 62H | 11H | EFH | |  | 000001 | 100000 | 00010 | 00010001 | 08H | 11H | 01010011 | EFH | 11H | 00H | | ADD R0,R1 | 100001 | 000001 | 10000 | 01110010 | 09H | 11H | 00010001 | EFH | 23H | 12H | |  | 000001 | 100000 | 00010 | 01110010 | 09H | 11H | 00010001 | 12H | 23H | 00H | | JC 0CH | 100111 | 010010 | 00100 | 01001000 | 0AH | 11H | 01110010 | 12H | 12H | 00H | |  | 010011 | 000001 | 10000 | 01001000 | 0AH | 11H | 01110010 | 12H | 12H | 00H | |  | 000001 | 100000 | 00010 | 00110001 | 0CH | 11H | 01110010 | 12H | 12H | 00H | | AND R0,R1 | 100011 | 000001 | 10000 | 10100010 | 0DH | 11H | 00110001 | 12H | 23H | 02H | |  | 000001 | 100000 | 00010 | 10100010 | 0DH | 11H | 00110001 | 02H | 23H | 00H | | OUT R2 | 101010 | 000001 | 10000 | 11100000 | 0EH | 11H | 10100010 | 02H | 12H | 12H | |  | 000001 | 100000 | 00010 | 11100000 | 0EH | 11H | 10100010 | 02H | 12H | 00H | | STP | 101110 | 000001 | 10000 | 10000101 | 0FH | 11H | 11100000 | 02H | 02H | 00H |   **记录连续方式下的结果：**  1. 寄存器值：  - R0 = 02H  - R1 = 23H  - R2 = 12H  - R3 = 11H  2. 存储器值：  - [12H] = 62H  - [13H] = 47H   1. **实验收获及体会**   通过本次实验，我深入理解了CPU微程序控制器的工作原理及其对数据通路的控制机制，掌握了机器指令与微指令的对应关系，能够准确分析指令执行过程中各寄存器和存储单元的状态变化。在实验操作中，我熟练掌握了手工汇编、单步调试和连续运行等调试技巧，培养了严谨的计算机系统思维，对指令取指、译码、执行的全过程有了更直观的认识。同时，通过观察跳转指令和运算指令对标志位的影响，我进一步理解了程序流程控制的实现原理，这些收获为我后续学习计算机体系结构和操作系统奠定了重要的实践基础  **实验六、中断原理实验**   1. **实验任务及目的**   实验任务：   理解中断相关指令，以及每个信号的意义和变化条件；   将主程序和中断服务程序手工汇编成二进制机器代码；   通过简单的连线构成能够运行程序的TEC-8模型计算机；   将主程序和中断服务程序装入存储器，给寄存器R1赋初值01H，R0赋初值0；   执行三遍主程序和中断服务程序，详细记录中断有关信号变化情况，特别记录好断点和R0的值；   将主程序中地址为00H的EI指令改为DI，重新运行程序，记录现象。   1. **程序的手工汇编结果（包括主程序和中断服务程序）**      1. **实验过程及结果**  |  |  |  | | --- | --- | --- | | 执行程序顺序 | PC断点值 | 中断时的R0 | | 第1遍 | 00000110 | 00010110 | | 第2遍 | 00000101 | 00101100 | | 第3遍 | 00000010 | 01101001 |  1. **实验收获及体会**   通过本次实验，我深入理解了中断机制的工作原理，掌握了中断请求、响应、断点保护和恢复的全过程，能够准确分析中断信号的变化条件和时序关系。在实验操作中，我通过多次执行主程序和中断服务程序，观察到中断发生时PC断点值和寄存器R0的变化规律，验证了中断嵌套和优先级处理的实现方式。通过修改EI指令为DI指令的操作，我直观认识到中断允许控制对程序执行流程的关键影响，这些实践不仅加深了我对中断原理的理解，更培养了我分析和调试硬件中断系统的能力，为后续学习计算机体系结构和实时系统开发奠定了重要基础。 |

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