

METHOD OF OPERATING AND INDUCTION
MOTOR CONTROL SYSTEM

11 The present invention relates to an improved control
12 system for AC induction motors and, in its preferred embodiment,
13 to an improved digital induction motor control system.

15 A prior art digital induction motor control system is
16 shown in U. S. Patent No. 4,361,792 issued November 30, 1982
17 and assigned to the assignee of the instant application. The
18 system disclosed in that prior art patent derives a calibrated
19 phase angle and then controls the operation of the motor based
20 on that phase angle, irrespective of variations in motor
21 loading. In this way energy consumption is reduced. Referring
22 to Fig. 1 of U. S. Patent No. 4,361,792, after the motor has
23 gotten up to speed the count in incremental counter 38 and delay
24 counter 36 is zero. The number in phase angle counter 34
25 corresponds to the phase angle between motor voltage and motor
26 current zero crossings. The count in the incremental counter
27 is incremented every other cycle, which causes the count in the
28 delay counter to be similarly increased. This increased delay
29 in firing the triac reduces the phase angle and, therefore, the
30 count in the phase angle counter. Eventually, the number in the

1 phase angle counter will be approximately equal to the number
2 in the delay counter. The number in the phase angle counter
3 can then be stored in the phase angle register as the calibrated
4 phase angle and used to operate the system.

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6 Deriving the calibrated phase angle in this manner,
7 however, means that the number stored in the phase angle
8 register as the calibrated phase angle depends, in part, on
9 the initial motor loading. Greater power savings can be
10 obtained if the motor happens to be heavily loaded when the
11 calibrated phase angle was derived. The prior art also
12 discloses how to modify the initial calibrated phase angle
13 so as to yield a refined calibrated phase angle. See column 5,
14 line 3 through column 6, line 3 of U. S. Patent No. 4,361,792.

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3 The present invention represents an improvement over
4 the invention of U. S. Patent No. 4,361,792. As noted in that
5 patent, the application was based on limited experimentation.
6 Based on extensive experimental work applicants have developed
7 a new and improved method for controlling AC induction motors.
8 Applicants have discovered that changes in both the phase angle
9 and the firing delay result from changes in motor load and that
10 these changes occur in a characteristic manner which is common
11 to AC induction motors. This characteristic may be approximated
12 by an equation of the form $y = mx + b$, where y is the phase
13 angle, x is the firing delay, m is the slope and b is the
14 offset. Applicants have also discovered how this characteristic
15 may be used to control AC induction motors with substantial
16 energy savings.

17
18 In addition, applicants have discovered a way to
19 optimize energy savings by means of a "perturbation" technique
20 in which the firing delay is increased by a predetermined
21 amount and the behavior of the phase angle is evaluated for
22 several cycles. If the result of the evaluation indicates
23 that additional energy savings are possible, the firing
24 delay is again increased by a predetermined amount and the
25 behavior of the phase angle is again monitored for several
26 cycles. This process is repeated until energy savings
27 are maximized.

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Fig. 1A is a flow diagram depicting the operation of a motor control system in accordance with the present invention;

Fig. 1B comprises graphs of typical motor responses when controlled in accordance with the present invention;

Fig. 2 is a schematic diagram of a preferred motor control system which may be used to implement the present invention;

Fig. 3 is a schematic diagram of another motor control system which may be used to implement the present invention;

Figs 3A to 3F show details of the diagram of Fig. 3.

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3 As already noted, the present invention is based on
4 applicants' discovery that AC induction motors share a common
5 characteristic, namely, that changes in phase angle and firing
6 delay with variations in motor load can be approximated by the
7 formula $y = mx + b$, where y is the phase angle, m is the slope,
8 x is the firing delay and b is the offset. A preferred equation
9 which has been found applicable to all single-phase AC induction
10 motors tested is $PA = - 0.12 DLY + 70$. Implementation of this
11 equation permits control of the motor with substantial energy
12 savings. In the equation, PA and DLY are expressed in units
13 of count. In the illustrative embodiment of the invention
14 shown herein, 1 count is equal to 30 microseconds or 0.648
15 electrical degrees at 60 Hertz.

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17 Figure 1A discloses generally how the motor is control-
18 led in accordance with the equation $PA = - 0.12 DLY + 70$. At
19 event N , the motor is energized using a firing delay D_n . The
20 phase angle PA_n is then measured. The sum of S_n of the delay D_n
21 and the phase angle PA_n is then used as the address for a computer-
22 generated look-up table. The contents of that address PA_t (phase
23 angle table) is compared with the previous phase angle PA_n and
24 the result used either to increase or decrease the delay.
25 Initially, PA_n will be greater than PA_t and the delay will be in-
26 creased in accordance with the formula $D_{n+1} = (PA_n - PA_t)/2 + D_n$.
27 This increased delay in energizing the motor results in energy
28 savings. The process is repeated until PA_t and PA_n are
29 approximately equal. If the motor load increases, PA_t will
30 exceed PA_n . Now the delay will be reduced in accordance with

1 the formula $D_{n+1} = D_n - 4(PA_t - PA_n)$. This reduced delay in
2 energizing the motor results in more power being delivered to
3 the motor to handle the increased load and ensures that the
4 motor continues to operate at its designed, constant speed.

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6 Table I, set forth on the next page, is a computer
7 generated look-up table based on the equation $PA = - 0.12 DLY + 70$
8 The sum of the phase angle PA and the delay DLY is used as the
9 table entry point for initial motor control. The entries in the
10 table are phase angles, i.e., PA_t . Thus, if the sum of PA
11 and DLY is 100 ($100 + 0$), the phase angle from the table is 65.
12 If $PA + DLY = 106$ ($100 + 6$), $PA_t = 64$. Similarly, if $PA + DLY =$
13 193 , $PA_t = 53$; whereas if $PA + DLY = 194$, $PA_t = 52$. The table
14 provides for 256 sum entry points and these 256 entry points
15 are divided into 16 groups or levels, with 16 entry points in
16 each level. Thus, sum 0 through 15 form Level 1, sums 16
17 through 32 form Level 2, etc. It should be noted that small
18 entry sums indicate high motor loads whereas large sums
19 indicate low motor loads. It should also be noted that the
20 firing delay is never less than 1. Thus, in Levels 1 through
21 4 the 100 indicates that a firing delay of 1 is to be
22 maintained.

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TABLE 1

(PA = - .12 DLY + 70)

LEVEL	Sum	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9
1	0 10	100 100	100 100	100 100	100 100	100 100	100 100	100 100	100 100	100 100	100 100
2	10 20 30	100 100	100 100	100	100	100	100	100 100	100 100	100 100	100 100
3	30 40	100	100	100 100	100 100	100 100	100 100	100 100	100 100	100	100
4	40 50 60	100 100	100 100	100 100	100 100	100	100	100	100	100 100	100 100
5	60 70	69	69	69	69	100 69	100 69	100 69	100 68	100 68	100 68
6	80 90	68 67	68 67	68 66	68 66	67 66	67 66	67	67	67	67
7	90 100 110	65 64	65 64	65	65	65	65	66 64	66 64	66 64	65 64
8	110 120	63	62	64 62	64 62	63 62	63 62	63 62	63 62	63	63
9	120 130 140	61 60	61 60	61 60	61 59	61	61	60	60	61 60	61 60
10	140 150	58	58	58	58	59 58	59 58	59 58	59 58	59 57	59 57
11	160 170	57 56	57 56	57 55	57 55	57 55	56 55	56	56	56	56
12	170 180 190	54 53	54 53	54	54	54	54	55 54	55 53	55 53	55 53
13	190 200	52	52	53 51	53 51	52 51	52 51	52 51	52 51	52	52
14	200 210 220	50 49	50 49	50 49	50 49	50	50	49	49	51 49	50 49
15	220 230	48	48	48	48	48 48	48 48	48 48	48 48	48 48	48 48
16	240 250	48 48	48 48	48	48	48 48	48 0	48	48	48	48

1 It will be appreciated that a different table can be
2 generated by varying the slope from - 0.12 to some other value
3 such as - 0.18 or by varying the offset from 70 to some other
4 value such as 68. A different table could also be generated by
5 varying both the slope and the offset. For example, applicants
6 have controlled single-phase AC induction motors based on a
7 table generated in accordance with the formula $PA = - 0.18 DLY$
8 $+ 72$. The slope may vary between about - 0.2 and about - 0.1,
9 while the offset may vary between about 65 and about 72. Appli-
10 cants will now show, by means of a specific example, how the
11 motor is controlled using this type of equation.

12
13 Initially, the computer determines the existing phase
14 angle PA , adds the start-up firing delay of 1 to PA , and uses
15 this sum to enter the table. The computer then reads the phase
16 angle in the table, which corresponds to this table entry sum
17 and calculates a new firing delay. If $PA_1 = 99$, then $PA_1 + DLY_1$
18 $= 99 + 1 = 100$. Referring to Table 1, address 100 contains a
19 PA_t of 65. Since PA_1 is greater than PA_t , the new firing delay
20 is calculated as follows: new delay $= (PA_1 - PA_t)/2 + \text{old delay}$
21 $= (99 - 65)/2 + 1 = 18$. The new firing delay of 18 is now
22 implemented and the resulting phase angle is measured, in this
23 case 95. The new entry sum is $95 + 18 = 113$, which gives a
24 PA_t of 64. The new delay is $(95 - 64)/2 + 18 = 33$. This
25 process continues and eventually, assuming that the motor load
26 does not change, a point in the table will be reached where the
27 sum remains fairly constant, i.e., PA_t approximately equals
28 PA_n . If, however, PA_t exceeds PA_n , this indicates an increase
29 in motor loading. The firing delay is then reduced by the
30 amount $4(PA_t - PA_n)$. See Fig. 1A.

1 The foregoing motor control technique provides a smooth
2 response to clutched loads without risk of motor stall and without
3 having to respond with full power, which is an inefficient response
4 unless absolutely necessary. The motor automatically responds to
5 load changes, in either direction, finding its proper position
6 in the table for increased energy efficiency. While this basic
7 approach has been proven effective in increasing the energy
8 efficiency of all motors tested, many motors possess the potential
9 for even greater energy savings. This is due to the fact that
10 such motors deviate from the empirical formula $PA = - 0.12 DLY$
11 $+ 70$: (1) having a slope other than $- 0.12$; (2) having an
12 offset other than 70; (3) having the phase angle and/or delay
13 vary non-linearly with load; or (4) a combination of the foregoing.
14 In order to optimize the energy efficiency of all motors, a
15 further motor control technique has been developed. This
16 involves "perturbing" the motor operation by introducing an
17 additional predetermined delay in energizing the motor, observing
18 the behavior of the phase angle for several cycles in response
19 to the delay, and then controlling the motor based on the nature
20 of the phase angle response.

21
22 After initial control of the motor has been accomplished
23 in accordance with Fig. 1A and Table 1, an additional firing
24 delay of 20 counts is added to the existing delay. The effect
25 of this additional delay on the phase angle is then determined.
26 This is accomplished by measuring and storing the value of PA at
27 T_0 (when the 20 count firing delay is added) and at $T_1, T_2, T_3,$
28 T_4 and T_5 (the next 5 positive-going zero crossings of motor
29 current). PA_0 is the phase angle at T_0 , PA_1 the phase angle
30 at T_1 , etc.

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1 As shown in Fig. 1B, there are three basic types of
2 responses to increasing the firing delay by a predetermined
3 amount. In a Type I response, the phase angle is reduced from
4 PA_0 to PA_1 and then remains between PA_1 and $(PA_0 - PA_1)/3$, i.e.,
5 it recovers to less than 1/3 of the difference between PA_0 and PA_1 .
6 In a Type II response, the phase angle is reduced from PA_0 to PA_1
7 and then recovers to more than 1/3 of the difference between
8 PA_0 and PA_1 . In a Type III response, the phase angle is
9 initially reduced from PA_0 to PA_1 and then further decreases
10 to a level of $PA_1 - 2$. In the event of a Type III response,
11 the calibration procedure is aborted and the computer controls
12 the motor based on the conditions in effect at time T_0 . In the
13 event of a Type II response, the computer temporarily classifies
14 the delay at T_0 (the delay in effect before introducing the
15 additional 20 count delay) as the optimum delay for maximum
16 energy savings at that load and at those operating conditions
17 (e.g., temperature, supply voltage, etc.). The computer will,
18 however, repeat the process several times to verify that a Type II
19 response continues to be obtained. A Type I response indicates
20 that it may be possible to obtain additional energy savings.
21 In that event, the computer increments the firing delay and
22 evaluates the response of the phase angle until a Type II or
23 Type III response is obtained, i.e., until operating energy
24 efficiency has been maximized.

25
26 Referring again to Table 1, the calibration process
27 for optimizing energy efficiency is generally conducted at
28 Levels 6 - 13. For convenience Table 1, which has an offset
29 of 70, is referred to as a "70 Table." Experimentation to date
30 has shown that all single-phase AC induction motors tested will



1 operate satisfactorily, at all loads, using the 70 Table. Motors
2 that produce a Type I response, which indicates that additional
3 energy savings may be possible, are assigned smaller phase angles
4 corresponding to their look-up table entry sums. This is done,
5 each time there is a Type I response, by decrementing the offset.
6 In other words, when a Type I response is obtained the equation
7 is changed from $PA = - 0.12 DLY + 70$ to $PA = -0.12 DLY + 69$.

8
9 For example, assuming that the motor is operating at a
10 look-up table entry sum of 140, this corresponds to a PA_t of 60.
11 If a Type I response is obtained, a new calculation is made based
12 on the equation $PA = - 0.12 DLY + 69$. This yields a PA_t of 59
13 for a look-up table entry sum of 140. If another Type I response
14 is obtained, a new calculation is made based on the equation
15 $PA = - 0.12 DLY + 68$. This yields a PA_t of 58 for a look-up
16 table entry sum of 140. The effect of this procedure, for a
17 constant look-up table entry sum, is to increase the firing delay
18 and reduce the power delivered to the motor, thereby increasing
19 energy savings. This procedure is repeated until a Type II
20 response is obtained, indicating that energy savings have been
21 maximized. In the illustrative embodiment of the invention dis-
22 closed herein, the minimum allowable offset (maximum energy
23 savings point) has been limited to 60. A Type III response
24 indicates either that the motor load is increasing or that
25 maximum energy savings have been obtained. In either case,
26 further calibration is halted until stable operation resumes.

27
28 Referring to Table I, the calibration process for
29 maximizing operating energy efficiency is limited to Levels
30 6 - 13. It is possible that some motors, in certain applications,

1 will operate at one constant load point, thus limiting calibration
2 to a look-up table entry sum corresponding to that load point.
3 Even with a constant load, however, fluctuations in supply
4 voltage, operating temperature, motor friction, etc. will cause
5 the table entry sums to vary somewhat, thus creating the likeli-
6 hood a motor varying from one level to another. When this
7 occurs experimentation has shown that when the offsets between
8 adjacent levels differ by more than 5, and the motor is
9 oscillating between such levels, a discernable "bump" is
10 produced which could be disconcerting to the user. Accordingly,
11 applicants have devised the following technique for adjusting
12 the offsets of adjacent levels so that they never differ by
13 more than 3.

14
15 Returning to the preceding example, the table entry
16 sum was 140. This corresponds to Level 9 in Table 1. When
17 the calibration procedure is commenced and a Type I response is
18 obtained, the computer changes the offset for Level 9 to 69.
19 None of the other levels is affected. If another Type I
20 response is now obtained, the Level 9 offset is dropped to 68.
21 This continues until one half the difference between the
22 offsets of adjacent levels is equal to or exceeds 3. When
23 that occurs, one half the difference is applied to the adjacent
24 level, differences being rounded up. In the foregoing example,
25 the first adjustment of adjacent levels occurs when the offset
26 for Level 9 reaches 65. Then $\frac{70 - 65}{2} = 2.5$, which is rounded up
27 to 3. At this point, Levels 8 and 10 are assigned offsets of 67.
28 When the offset for Level 9 reaches 62, the offsets for Levels
29 8 and 10 are adjusted to 64. Since Levels 7 and 11 now differ
30 from Levels 8 and 10 by more than the permitted amount, the

1 offsets for Levels 7 and 11 are adjusted to 67. The offset for
2 Level 9 can now go down to 60 (the lowest permitted in this
3 illustrative embodiment of the invention), without necessitating
4 any further adjustments of the offsets of the adjacent levels.
5

6 If the motor continues to operate at Level 9, no other
7 calibration attempt will occur. If, however, the motor load
8 changes, causing entry to another level, the computer will
9 compare the new offset with 60 (the previous offset) and will
10 permit a sufficient number of calibration steps to occur so
11 that an offset of 60 could be reached. For example, if the
12 motor shifts to Level 7, which has an offset of 67, the
13 computer will permit 7 calibration attempts to be executed.
14 Levels 1 through 4 never deviate from a maximum firing delay
15 of 1 while Levels 5, 14, 15 and 16 are never calibrated. They
16 are, however, allowed to have their offsets adjusted based
17 on the calibration of an adjacent level.
18

19 Fig. 2 discloses one motor control system which may
20 be used to implement the present invention. Fig. 2 of the
21 instant application is the same as Fig. 2 of U. S. Patent
22 No. 4,361,792 and the description of Fig. 2 is incorporated
23 herein by reference. The present invention has been employed
24 to control single-phase AC induction motors using the system
25 shown in Fig. 2. A suitable computer program for practicing
26 the present invention with the system shown in Fig. 2 is
27 included at the end of the instant specification.
28

29 While the present invention has been described in
30 terms of its application to single-phase AC induction motors,

1 it may also be applied to 3-phase induction motors. For a
2 description of a 3-phase digital motor control system see
3 Column 6, lines 25-38 of U. S. Patent No. 4,361,792, which is
4 incorporated herein by reference. Based on more limited
5 experimentation applicants have discovered that 3-phase AC
6 induction motors also experience changes in phase angle and
7 firing delay as a function of changes in motor load which vary
8 in a characteristic manner and may be approximated by the
9 expression $y = mx + b$. Again y is the phase angle, m is the
10 slope, x is the firing delay and b is the offset. Unlike the
11 case of single-phase AC induction motors, with a 3-phase AC
12 induction motor m is positive. A preferred equation for
13 controlling 3-phase AC induction motors is $PA = + 0.62 DLY + 24$.
14 With 3-phase AC induction motors the slope may vary from
15 0.5 to 0.7, while the offset may vary from 10 to 30.

16
17 It will be appreciated by those skilled in the art that
18 the present invention is not limited to the specific illustrative
19 embodiment disclosed herein. Thus, while applicants have
20 disclosed that for single-phase AC induction motors value for m
21 can be selected between - 0.1 and - 0.2 and values for b can
22 be selected between 65 and 72, values can also be selected
23 outside these ranges and still successfully control many motors.
24 Similarly, while applicants have disclosed that for 3-phase AC
25 induction motors values for m can be selected between 0.5 and 0.7
26 and values for b can be selected between 10 and 30, values can
27 also be selected outside these ranges and still successfully
28 control many motors. Other modifications and improvements
29 within the scope of the present invention will also be apparent
30 to persons skilled in the art. For example, the present



1 invention may be implemented without using a programmed digital
2 computer.

3
4 Fig. 3 of the present application discloses such a
5 motor control system. In Fig. 3 Q1 through Q15 are FET
6 transistors which conduct when a positive voltage is applied
7 to their gates, while Q16 is a triac such as a Teccor Q4025V5 and
8 Q17 is a diode bridge. The components designated U1 - U6,
9 U8 - U12, U14 - U16, U20, U21, U26, U27, U28 - U30, U38 - U39,
10 U41 - U44, U60, U64, U72, U73 and U78 are operational amplifiers.
11 U13, U31 - U33, U48, U53, U65 and U79 are inverters, while U56
12 is a non-inverting amplifier. U17, U22, U24, U25, U35, U36,
13 U46, U47, U49, U66, U68, U71, U74 and U80 are AND gates, while
14 U50, U52, U61 and U69 are OR gates. U45 is a NOR gate. U54,
15 U55, U57 - U59, U75 and U81 are CMOS Schmidt trigger amplifiers.
16 U18, U51, U67 and U70 are latches, with U67 configured to
17 divide by two. U19, U23, U37 and U62 are counters, U62 being
18 an up/down binary counter. U63 is a four-line decoder which
19 performs a D/A conversion based on the output from U62. U76 is
20 a buffer amplifier, such as a TI 7406, and U77 may be a Monsanto
21 6200 IC chip comprising a pair of optically coupled SCRs connected
22 as a triac. A brief description of the operation of the motor
23 control system of Fig. 3 is set forth below.

24
25 U64 is connected to the line voltage and develops a
26 squared-up voltage waveform. Q17 and U78 develop a square
27 waveform which is positive when Q16 is off. U66 produces a
28 positive pulse which is synchronized with the line voltage.
29 The output from U66 is used to derive two system timing
30 signals. The first is produced by U53. The second is produced

1 by U54 and U55 and follows closely in time the output of U53.
2 Two additional timing signals are derived from the output from
3 U64. One is produced by U56, U57 and U81 while the other is
4 produced by U58 and U59 and follows closely in time the output
5 of U57. The timing for the sample-and-hold circuits Q11/U26
6 and Q12/U27 is provided by U13 and U22 - U25. Finally, U35,
7 U36 and U37 control the gating of the various types of responses
8 (Type I, Type II or Type III) when the motor operation is
9 perturbed to maximize operating efficiency.

10

11 Converting the phase angle pulse width to a voltage
12 is performed by Q1, Q9 and U1. The output of U1 is PA_n which
13 is supplied, inter alia, to the sample-and-hold circuits. The
14 "delay" pulse width is converted to a voltage by Q2, Q10 and U2.
15 U3 and U4 take the output of U2 and multiply it by "m" and add
16 "b," respectively. The output of U4 is therefore PA_t . U5
17 compares PA_n with PA_t . The output of U5 is positive when PA_n
18 is greater than PA_t and negative when PA_t is greater than PA_n .
19 U5 controls whether the firing delay is increased or decreased.
20 When the output of U5 is positive, Q3 is enabled and Q13 is
21 disabled and U6 and U8 perform the operation $(PA_n - PA_t)/2 + D_n$.
22 When the output of U5 is negative, Q3 is disabled and Q13 is
23 enabled and U28, U29 and U30 perform the operation
24 $D_n - 4(PA_t - PA_n)$.

25

26 The combination of U14, U15 and U16 function as a
27 zero error detector, i.e., they determine when PA_n equals PA_t .
28 When the output of both U16 and U15 are positive, the
29 perturbation sequence is initiated. The perturbation sequencing
30 circuitry is formed by U17, U18, U19, U50, U51, U20, U21, U32,

1 Q4 and Q5. U18 functions as a "perturbation in progress" latch.
2 U19 keeps track of the number of perturbations that have been
3 initiated. U38 and U39 perform the operation $(PA_0 - PA_1)/3 + PA_1$.
4 U41 compares the output of U40 with PA_n . If PA_n is greater than
5 PA_1 plus $(PA_0 - PA_1)/3$, then the output of U41 is positive and
6 indicates a Type II response. U43 and U42 perform the operation
7 $PA_1 - 2$ and U44 compares this with PA_n . If PA_n is greater than
8 $PA_1 - 2$, then the output of U44 is positive and indicates a
9 Type III response. The outputs of U41 and U44 are supplied to
10 NOR gate U45 which produces a positive output indicative of a
11 Type I response in the absence of both a Type II and a Type III
12 response.

13
14 The gating of the various responses is controlled by
15 U46, U47, U49 and U68. Type I and Type II responses are gated
16 by U49 and U68 respectively. A Type III response which occurs
17 during the first perturbation is gated by U47 while one that
18 occurs in a subsequent perturbation is gated by U46. An output
19 from either U46 or U47 will produce an output from U52 which
20 will reset the "perturbation in progress" latch U18 via OR
21 gate U69. When U49 indicates a Type I response, this causes
22 counter U62 to decrement the offset.

23
24 The delay timing for controlling the delay in firing
25 the triac comprises U9, U10, U11, U12, U33, Q6, Q7, Q8, Q14
26 and Q15. U10 and U12 are ramp generators which produce the
27 same fixed ramp starting when the triac current goes to zero
28 during each half cycle of the line voltage. U11 compares these
29 ramps with the new delay in U9. The output of U11 goes
30 positive at the end of the new delay. The output from U11 is

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1 buffered by U76 and fires triac Q16 via trigger U77. U72, U73
2 and U75 determine when a change in line voltage or motor loading
3 is great enough to merit a new perturbation sequence, and initiate
4 same.

5
6 As already noted, this and other circuitry for
7 implementing applicants' invention will be apparent to persons
8 skilled in the art. Applicants' invention is defined by the
9 claims which follow.

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ASM48 : F1:PFCNTL SRC MACROFILE (REF PRINT(:F9:PFCNTL LBT)

ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V3.0

PAGE

1

FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V. M-9.5

LOC. OBJ.

LINE

SOURCE STATEMENT

1 *TITLE('FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V. M-9.5')
2 *INCLUDE(:F0:CP1STD.801)
3 *EJECT

41

1818-11 NCS-48/1-41 MACRO ASSEMBLER, V3.0. PAGE 2
FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V. M-9.5

LOC	OBJ	LINE	SOURCE STATEMENT
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		6	
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		20	*****
		21	\$EJECT

IS18-11 MCB-48/UPI-41 MACRO ASSEMBLER, V3.0 PAGE 3
FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V.M-9.5

LOC	OBJ	LINE	SOURCE STATEMENT
		22	\$NOCOND
		23	,
FFFF		24	TRUE EGU OFFFFH
0000		25	FALSE EGU 0000H
		26	,
FFFF		27	DEMO EGU TRUE
0000		28	DEBUG EGU FALSE
		30	\$EJECT

1818-II MCS-48/LPI-41 MACRO ASSEMBLER, V3.0 PAGE 4
FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V.M=9.5

LOC	OBJ	LINE	SOURCE STATEMENT
31			*****
32			
33			FOR REFERENCE PURPOSES THE PROTOTYPE CONTROLLER HAS
34			A DIP SWITCH ON THE BUS PORT, THE FOLLOWING DIAGRAM
35			DEFINES THE LOGIC OF THE SWITCHES:
36			
37			
38			F-T
39			BIT
40			FUNCTION
41			TRUE
42			FALSE
43			
44			
45			
46			
47			
48			
49			
50			F=FALSE
51			T=TRUE
52			*****
53			
54			SEJECT

IS18-II MCS-4B/UP1-41 MAGRO ASSEMBLER, V3.0 PAGE 5
FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V M-9.5[illegible]

```

55  *****
56  MACRO DEFINITIONS
57  *****
58  *****
59  FILL MACRO ENDAD V.M=1.0
60  FILL MACRO V.M=1.0
61  *SAVE NOGEN
62  REPT ENDAD=3
63  DB 0
64  ENDM
65  *RESTORE
66  DB 0
67  ENDM
68  MACRO
69  NEG MACRO V.M=1.0
70  CPL A
71  INC A
72  ENDM
73  *****
74  *****
75  SEVENT

```

75 非ゼロ

1818-11 MCB-48/1-41 MACRO ASSEMBLER V3.0 PAGE 6
FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V M-9.5

LOC OBJ LINE SOURCE STATEMENT

```

76 | *****
77 |
78 | MCB 48 I/O UTILIZATION
79 |
80 | PORT 2
81 | BIT 7
82 | BIT 6
83 | BIT 4 VOLTAGE WAVE FORM SQUARED
84 | BIT 5 CURRENT WAVE FORM SQUARED
85 | BIT 3 THYRISTOR FIRING
86 | BIT 2
87 | BIT 1
88 | BIT 0
89 |
90 | PORT 1
91 | BIT 7
92 | BIT 6
93 | BIT 5
94 | BIT 4
95 | BIT 3
96 | BIT 2
97 | BIT 1
98 | BIT 0 SMOOTH START/STOP -> IF DEMO EQ. TRUE
99 |
100 | BUS PORT
101 | BIT 0 START/STOP -> IF DEMO EQ. TRUE
102 | BIT 1 FULL POWER ONLY -> IF DEMO EQ. TRUE
103 | BIT 2 BASIC TABLE ONLY -> IF DEMO EQ. TRUE
104 | BIT 3 TO
105 | BIT 7 UNUSED
106 |
107 | TIMER/COUNTER
108 | 33.3 KHZ CLOCK
109 |
110 | *****
111 | SEJECT *****

```

(S)

ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V3.0 PAGE 7
FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V.M-9.5

LOC	OBJ	LINE	SOURCE STATEMENT
		112	*****
		113	
		114	PROGRAM EQUATES
		115	
0038		116	IP2 EQU 00111000B ; INITIAL PORT 2 STATE
00F7		117	TROFF EQU 11110111B ; TURN OFF THYRISTOR
0008		118	TRON EQU 00001000B ; TURN ON THYRISTOR
00D6		119	MAXHT EQU 214 ; MAX WAIT COUNT FOR CURRENT ZERO CROSS
001E		120	HLDOFF EQU 30 ; HOLD OFF FOR DECREASING LOAD RESPONSE
0005		121	VLTDEN EQU 5 ; VOLTAGE ZERO CROSSING DEBOUNCE LOOP
000A		122	MAXOFFS EQU 10 ; MAXIMUM OFFSET ALLOWED
FFF6		123	OFSLIM EQU -10 ; MAXIMUM OFFSET ALLOWED, USE -N
003C		124	INTVLC EQU 60 ; INTERVAL BETWEEN CALIBRATIONS
0005		125	CALCYC EQU 5 ; NUMBER OF CALIBRATION CYCLES
000A		126	SMNUMB EQU 10 ; NUMBER OF ELEMENTS TO SMOOTH
		127	
		128	*****
		129	
		130	RAM ALLOCATION MAP
		131	
		132	*****
		133	
0020		134	BEGRAM EQU 20H ; BEGINNING OF USABLE RAM ADDRESS
		135	
		144	
		145	THE ADDRESSES OF CALLIM AND SMSTAD MUST BE EXACTLY
		146	16 APART. THE CODE ASSUMES THIS.
		147	
0024		148	CALLIM EQU 24H ; SAVE AREA FOR CAL UP LIMITS
002F		149	OFFPT EQU 2FH ; CURRENT OFFSET POINT IN THE SUMTAB
0030		150	OFFTAB EQU 30H ; OFFSET TABLE, 32 NIBBLES CT. OFF
0034		151	SMSTAD EQU OFFTAB+4 ; ADDRESS TO START SMOOTHING
003F		152	ENDRAM EQU 3FH ; END OF RAM MEMORY ADDRESS
		153	
		154	*****
		155	
		156	REGISTER UTILIZATION
		157	
		158	*****
		159	
		160	R0:
		161	R0-INDEX
		162	R1-CYCLE COUNT
		163	R2-CALIBRATE
		164	R3-PHASE ANGLE COUNT
		165	R4-DELAY COUNT SAVE
		166	R5-OPTIMUM PHASE ANGLE
		167	R6-DAMPENING COUNTER
		168	R7-CALIBRATE
		169	R8:
		170	R0-SMOOTHING POINTER
		171	R1-
		172	R2-EDGE MACRO
		173	R3-EDGE MACRO/SMOOTHING
		174	R4-SMOOTHING

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ISIS-II MCS-48/UP1-41 MACRO ASSEMBLER, V3.0 PAGE 8
FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V. M-9.5

LOC	OBJ	LINE	SOURCE STATEMENT
		175 ;	R5-SMOOTHING
		176 ;	R6-
		177 ;	R7-
		178 ;	
		179 ;	*****
		180	\$EJECT

1818-II MCS-48/UP1-41 MACRO ASSEMBLER, V3.0 PAGE 9
FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V.M-9.5

LOC	OBJ	LINE	SOURCE STATEMENT
		181	*****
		182	
		183	LOW MEMORY VECTORS
		184	
		185	*****
		186	
0000		187	ORG OH ; PROGRAM START ON EXTERNAL RESET
0000 042F		188	JMP INIT ; START UP VECTOR
0002 6D		189	DB 06DH ; FILLER
0003 44B3		190	JMP EXT1 ; EXTERNAL INTERRUPT VECTOR
0005 6A		191	DB 06AH, 057H ; FORCES CHECKSUM
0006 57			
0007 44B2		192	JMP TINT ; TIMER/COUNTER VECTOR
		193	
		194	*****
		195	
		196	COPYRIGHT NOTICE
		197	
0009 28432920		198	DB (c) 1982, 1983 CHESEBROUGH-POND'S INC.
000D 31393832			
0011 2C203139			
0015 38332043			
0019 48455345			
001D 42524F55			
0021 47482D50			
0025 4F4E4460			
0029 5320494E			
002D 432E			
		199	
		200	*****
		201	EEJECT

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1918-II MCS-48/UPT-41 MACRO ASSEMBLER, V3.0 PAGE 10
FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V.M-9.5

LOC	OBJ	LINE	SOURCE STATEMENT
		202	*****
		203	
		204	PROGRAM INITIALIZATION
		205	
		206	*****
		207	
		208	INIT
002F	C5	209	SEL R80 ; SELECT REGISTER BANK 0
0030	2300	210	MOV A, #0 ; SET A TO ZERO
0032	90	211	MOVX @R0, A ; SET BUS PORT TO HI-Z
0033	08	213	INS A, BUS ; CHECK SWITCHES ON BUS PORT
0034	37	214	CPL A ; MAKE FALSE A.1
0035	128D	215	JBO MSTOP ; STOP MOTOR
0037	2338	220	MOV A, #1P2 ; TURN ON THYRISTOR
0039	3A	221	OUTL P2, A ; EXECUTE
003A	B5	222	CLR F0 ; THIRD CALIBRATION PHASE NOT
003B	A5	223	CLR F1 ; SECOND CALIBRATION PHASE NOT
003C	27	224	CLR A ; CLEAR REGISTERS AND COUNTERS
003D	AA	225	MOV R2, A
003E	AB	226	MOV R3, A ; ZERO INITIAL PHASE ANGLE COUNT
003F	BC01	227	MOV R4, #1 ; SET INITIAL DELAY COUNT TO 1
0041	BD1E	228	MOV R5, #30 ; R5 IS USED DURING STARTUP AS
		229	; A DELAY COUNT FOR THE TIME-OUT
		230	; DURING THE RUN PHASE IT CONTAINS
		231	; THE MEASURED PHASE ANGLE
0043	BE1E	232	MOV R6, #HLD OFF ; R6 CONTAINS THE COUNT OF THE NUMBER
		233	; OF CYCLES TO HOLD OFF THE IMPOSITION
		234	; OF A NEW DELAY WHEN THE MOTOR IS
		235	; BEING UNLOADED. THIS PREVENTS
		236	; OSCILLATION.
0045	BF3C	237	MOV R7, #INTVLC ; SET CALIBRATION INTERVAL
		238	
		239	 CLEAR RAM
		240	
0047	B820	241	MOV R0, #BEGRAM ; BEGINNING RAM ADDRESS
0049	B91F	242	MOV R1, #ENDRAM-BEGRAM ; LENGTH
		243	CLEAR1
004B	B000	244	MOV @R0, #0 ; ZERO BYTE
004D	18	245	INC R0 ; NEXT ADDRESS
004E	E94B	246	DJNZ R1, CLEAR1 ; INDEX
		247	
		248	 INITIALIZE THE OFFSET TABLE
		249	
		250	SET THE UPPER NIBBLE TO THE NUMBER OF CALIBRATES
		251	ALLOWED FOR THE PARTICULAR RANGE
		252	SET THE LOWER NIBBLE AT AN OFFSET OF ZERO
		253	
0050	B830	254	MOV R0, #OFFTAB ; OFFSET TABLE ADDRESS
0052	B000	255	@R0, #000H ; =1
0054	18	256	INC R0 ; +1
0055	B000	257	@R0, #000H ; =2
0057	18	258	INC R0 ; +1
0058	B000	259	@R0, #000H ; =3
005A	18	260	INC R0 ; +1
005B	B000	261	@R0, #000H ; =4

ISIS-II MCS-48/UP1-41 MACRO ASSEMBLER, V3.0 PAGE 11
FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V.M-9.9

LOC	OBJ	LINE	SOURCE STATEMENT
005D	18	262	INC R0 ;+1
005E	B000	263	MOV ERO, #000H ;=5
0060	18	264	INC R0 ;+1
0061	B0A0	265	MOV ERO, #MAXOFS SHL 4 ;=6
0063	18	266	INC R0 ;+1
0064	B0A0	267	MOV ERO, #MAXOFS SHL 4 ;=7
0066	18	268	INC R0 ;+1
0067	B0A0	269	MOV ERO, #MAXOFS SHL 4 ;=8
0069	18	270	INC R0 ;+1
006A	B0A0	271	MOV ERO, #MAXOFS SHL 4 ;=9
006C	18	272	INC R0 ;+1
006D	B0A0	273	MOV ERO, #MAXOFS SHL 4 ;=10
006F	18	274	INC R0 ;+1
0070	B0A0	275	MOV ERO, #MAXOFS SHL 4 ;=11
0072	18	276	INC R0 ;+1
0073	B0A0	277	MOV ERO, #MAXOFS SHL 4 ;=12
0075	18	278	INC R0 ;+1
0076	B0A0	279	MOV ERO, #MAXOFS SHL 4 ;=13
0078	18	280	INC R0 ;+1
0079	B0A0	281	MOV ERO, #MAXOFS SHL 4 ;=14
007B	18	282	INC R0 ;+1
007C	B0A0	283	MOV ERO, #MAXOFS SHL 4 ;=15
007E	18	284	INC R0 ;+1
007F	B0A0	285	MOV ERO, #MAXOFS SHL 4 ;=16
		286	
		287	NOW WAIT APPROXIMATELY 10 SECONDS TO ASSURE THE MOTOR IS
		288	UP TO SPEED. THE 10 SECOND WAIT TIME IS ARBITRARY AND
		289	CAN READILY BE CHANGED TO ACCOMMODATE ANY START-UP TIME.
		290	
		291	WAIT:
0081	EAB1	292	DJNZ R2, WAIT ;COUNT DOWN = 256 - 255 = 30
0083	E8B1	293	DJNZ R3, WAIT ;LOOPS OR ABOUT
0085	E0B1	294	DJNZ R5, WAIT ;10 SECONDS
0087	D5	295	SEL RB1
0088	BF00	296	MOV R7, #0 ;PRESET R7
008A	C5	297	SEL RB0
		298	
008B	049B	311	
		313	JMP PHASE ;GO TO MAIN LOOP
		314	
		315	THIS ROUTINE STOPS THE MOTOR AND WAITS FOR THE START/STOP
		316	SWITCH TO GO TRUE THEN IT STARTS UP WITH INITIALIZATION.
		317	IN SOME APPLICATIONS THIS MAY BE AN IMPORTANT FEATURE.
		318	
		319	MSTOP:
008D	9AF7	320	ANL P2, #TROFF ;TURN OFF THE THYRISTOR
		321	MSTOP1:
008F	08	322	INS A, BUS ;LOAD THE SWITCHES
0090	122F	323	JBO INIT ;IF SW IS TRUE THEN GO START MOTOR
0092	048F	324	JMP MSTOP1 ;WAIT HERE
		325	
		326	THIS ROUTINE FORCES THE THYRISTOR ON UNTIL THE FULLON SWITCH
		327	IS TRUE
		328	
		329	FULLP:

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FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V.M-9.5

LOC	OBJ	LINE	SOURCE STATEMENT		
0094	9A08	330	ANL	P2.#TRON	; TURN ON THE THYRISTOR
		331	FULLP1		
0096	08	332	INS	A.BUS	; LOAD THE SWITCHES
0097	322F	333	JB1	INIT	; IF SWITCH TRUE THEN START OVER
0099	0496	334	JMP	FULLP1	; WAIT HERE
		335			
		337			
		338			
		339	*****		
		340	\$EJECT		

ISIS-II MCS-48/UP1-41 MACRO ASSEMBLER, V3.0 PAGE 13
FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V.M=9.5

LOC	OBJ	LINE	SOURCE STATEMENT
		341 ;	*****
		342 ;	
		343 ;	
		344 ;	THE MAIN PROGRAM LOOP STARTS HERE, CONTROL PASSES THRU THIS
		345 ;	POINT EVERY HALF CYCLE OF THE LINE VOLTAGE
		346 ;	
		347	PHASE
009B	08	349	INS A, BUS ; LOAD THE SWITCHES
009C	37	350	CPL A ; FORCE FALSE=1
009D	128D	351	JBO MSTOP ; IF START/STOP SW FALSE STOP MOTOR
009F	3294	352	JBI FULLP ; IF FULL POWER SW FALSE FULL POWER
00A1	D5	354	SEL RB1 ; USE RB1 FOR DEBOUNCE
00A2	8A08	355	MOV R2, #VLTDBN ; SET DEBOUNCE COUNT
		356 ;	
		357 ;	THE DEBOUNCING OF THE VOLTAGE ZERO-CROSSING ELIMINATES
		358 ;	NOISE GENERATED ERRONEOUS PHASE ANGLE MEASUREMENTS. IT
		359 ;	ALSO HAS THE EFFECT OF SKEWING THE PHASE ANGLE MEASUREMENTS
		360 ;	THIS SKEWING IS ACCOUNTED FOR IN THE CONTROL ALGORITHMS
		361 ;	
		362	DBNCE
00A4	0A	363	IN A, P2 ; CHECK VOLTAGE LEVEL
00A5	DF	364	XRL A, R7 ; OPPOSITE OF LAST LEVEL
00A6	929B	365	JB4 PHASE ; NO, KEEP LOOKING
00A8	EAA4	366	DJNZ R2, DBNCE ; YES, DEBOUNCE IT
00AA	FF	367	MOV A, R7 ; CPL LEVEL FOR NEXT TIME
00AB	37	368	CPL A ; AND
00AC	AF	369	MOV R7, A ; SAVE
00AD	C5	370	SEL R80 ; RESTORE R80 FOR NORMAL OPS
		371 ;	
		372 ;	NOW WE HAVE THE VOLTAGE ZERO CROSSING SO WE START THE
		373 ;	TIMER COUNTING 3008 CLICKS AND WAIT FOR THE CURRENT
		374 ;	TO CROSS ZERO. IN EFFECT WE ARE MEASURING THE TIME BETWEEN
		375 ;	THE TWO OR WHAT WE CALL PHASE ANGLE
		376 ;	
00AE	27	377	CLR A ; CLEAR PHASE ANGLE COUNT
00AF	62	378	MOV T, A ; CLEAR PHASE ANGLE COUNT
00B0	45	379	STRT CNT ; START COUNT
00B1	9AF7	380	ANL P2, #TROFF ; TURN OFF THYRISTOR
00B3	8932	381	MOV R1, #50 ; FOR NOISE IMMUNITY WE DELAY
		382 ;	LOOKING FOR THE CURRENT CROSSING
		383 ;	FOR APPROXIMATELY 250US
00B5	2400	384	JMP WAITP ; JUMP ACROSS PAGE BOUNDARY
		385 ;	
		386 ;	FORCE TO NEW PAGE
		387 ;	
		388	FILL 100H
		389+	FILL MACRO V.M=1.0
0100	00	468+	DB 0 ; MEMORY FILLED TO THIS POINT WITH 00H
0100		469	ORG 100H
		470 ;	
		471 ;	NOW A THE PROGRAM ENTERS A FIXED WAIT BEFORE THE CURRENT
		472 ;	IS SAMPLED. THIS IS IN EFFECT A WINDOWING TO SAMPLE FOR
		473 ;	THE CURRENT ZERO CROSSING ONLY AT APPROPRIATE TIMES.
		474 ;	
		475	WAITP:

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FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V.M=9.5

LOC	OBJ	LINE	SOURCE STATEMENT	
0100	E900	476	DJNZ R1, WAITP	WAIT 250US TO LOOK FOR CURRENT
0102	B9D6	477	MOV R1, #MAXWT	THE MAXIMUM WAIT FOR A ZERO CROSSING
		478		IS ALSO SET, IF IT DOES'NT OCCUR
		479		IN APPROXIMATELY 3MS WE ABORT AND
		480		CONTINUE WITH A DELAY OF 1
		481		
		482		NOW LOOK FOR THE CURRENT ZERO CROSSING BUT THIS WILL NOT GO ON
		483		FOREVER, THE VALUE OF MAXWT DETERMINED THE LONGEST TIME TO
		484		CONTINUE LOOKING. IF THE MAXWT PERIOD IS EXCEEDED THEN
		485		QUIT LOOKING AND EXIT
		486		
		487	WAITC:	
0104	0A	488	IN A, P2	CHECK FOR ZERO CROSS OF CURRENT
0105	37	489	CPL A	SHIFT FLAVOR
0106	B212	490	JB5 CUROX	OUT IT
0108	E904	491	DJNZ R1, WAITC	NO, KEEP LOOKING
		495		
		496		NO CURRENT ZERO CROSSING IN THE ALLOTTED TIME SO
		497		FORCE THE THYRISTOR ON AND EXIT
		498		
		499	DELO:	ZERO DELAY PROCEDURE
010A	2301	503	MOV A, #1	USE MIN-1 COUNT DELAY
010C	AC	504	MOV R4, A	SAVE THAT DELAY FOR NEXT TIME
010D	8A0B	505	ORL P2, #TRON	TURN ON THYRISTOR
010F	65	506	STOP TCNT	STOP THE COUNTER AND
0110	049B	507	JMP PHASE	RETURN TO MAIN LOOP
		508		
		509		A ZERO CROSSING HAS BEEN DETECTED
		510		
		511	CUROX:	
0112	65	512	STOP TCNT	STOP COUNTER
0113	42	513	MOV A, T	AND SAVE PHASE ANGLE
0114	AB	514	MOV R3, A	IN R3: R3
		515		
		516		NOW WE HAVE THE PHASE ANGLE SO BEGIN THE DELAY COUNTDOWN
		517		
0115	FC	518	MOV A, R4	LOAD THE CURRENT DELAY INTO
		519	NEG	
		520	MACRO V.M=1.0	
0116	37	521	CPL A	MAKE VALUE IN REG A
0117	17	522	INC A	TWO'S COMPLIMENT
0118	62	523	MOV T, A	AND
0119	45	524	STRT CNT	START THE TIMER
		525		
		526		ALL CHANGES IN THE APPLICATION OF THE PHASE ANGLE AND
		527		DELAY OCCUR ON THE POSITIVE HALF CYCLE, THIS AVOIDS
		528		PROBLEMS ASSOCIATED WITH THE ASSYMETRY OF THE WAVEFORMS
		529		
011A	0A	530	IN A, P2	LOOK AT THE VOLTAGE
011B	37	531	CPL A	SEE IF POS. HALF CYCLE
011C	923E	532	JB4 DELAY	NO, SO GO DELAY AND FILE THYRISTOR/SCR
011E	B6F2	533	JFO CAL3	TEST FOR READY TO DO 3RD CAL SECTION
0120	76F0	534	JF1 CAL2	TEST FOR READY TO DO 2ND CAL SECTION
		535		NOW CHECK IF INTERVAL HAS LAPSED TO
		536		TRY FOR FIRST CAL

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FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V.M-9.5

LOC	OBJ	LINE	SOURCE STATEMENT
0122	EF3E	537	DJNZ R7, DELAY ; IF RBO: R7 (INTERVAL) IS ZERO THEN
		538	; CHECK FOR FIRST CAL ELSE JUST GO
		539	; WAIT FOR DELAY AND FIRE THYRISTOR/SCR
0124	8F3C	540	MOV R7, #INTVLC ; RESET INTERVAL IN CASE WE EXIT FOR
		541	; ZERO COUNT
0126	FB	542	MOV A, R3 ; CALC CURRENT SUM
0127	6C	543	ADD A, R4 ; BY ADDING RBO: R3 (PHASE ANGLE) +
		544	; RBO: R4 (DELAY)
0128	53F0	545	ANL A, #OFFH ; DIVIDE SUM BY 16 TO POINT TO
012A	47	546	SWAP A ; PROPER CALIBRATE TABLE
012B	0330	547	ADD A, #OFFTAB ; NOW A=OFFTAB(SUM/16)
012D	882F	548	MOV RO, #OFFPT ; SAVE CURRENT POINT FOR CALIBRATE
012F	A0	549	MOV RO, A ;
0130	AB	550	MOV RO, A ; A=ADDRESS OF OFFSET TABEL
0131	F0	551	MOV A, RO ; GET COUNT, OFFSET
0132	47	552	SWAP A ; LOOK AT COUNT
0133	530F	553	ANL A, #OFFH ;
0135	C63E	554	JZ DELAY ; IF COUNT = ZERO THEN DO NOT TRY TO
		555	; CALIBRATE ANY FURTHER
0137	F0	556	MOV A, RO ; OTHERWISE
0138	47	557	SWAP A ; DECREMENT CAL COUNT BEFORE
0139	07	558	DEC A ; ATTEMPTING TO CAL
013A	47	559	SWAP A ; AND SAVE IN OFFSET TABLE
013B	A0	560	MOV RO, A ;
013C	24EE	561	JMP CAL1 ; GO CALIBRATE
		562	;
		563	; ALL OTHER PROCESSING IS DONE SO WAIT HERE FOR
		564	; TIMER TO LAPSE AND FIRE THE THYRISTOR
		565	DELAY: ;
013E	1642	566	JTF FIRE ; DELAY DONE, YES
0140	243E	567	JMP DELAY ; NO
		568	FIRE: ;
0142	8A08	569	ORL P2, #TRON ; FIRE THYRISTOR
0144	65	570	STOP TCNT ; STOP THE TIMER
0145	0A	571	IN A, P2 ; CHECK POS HALF CYCLE
0146	9250	572	JB4 DISPA ; IF POSITIVE HALF CYCLE
		573	; THEN GO IMPLEMENT TABLE
		574	; ELSE CHECK FOR CAL PHASE'S
0148	864E	575	JFO JMPPHS ; IF CAL ACTIVE THEN DO NOT
014A	764E	576	JF1 JMPPHS ; SMOOTH
014C	2493	577	JMP SMOOTH ; ELSE SMOOTH
		578	;
		579	; EXTRA JUMPS GO JUMP PAST PAGE BOUNDARY
		580	;
		581	JMPPHS: ;
014E	0498	582	JMP PHASE ; GO BACK AND WAIT FOR VOLTAGE
		583	;
		584	; AT THIS POINT IT IS THE POSITIVE HALF CYCLE AND IT
		585	; IS NOT TIME TO CALIBRATE SO THE CURRENT SUM IS
		586	; CHECKED AND IF IT DOES NOT EXCEED THE BOTTOM LIMIT
		587	; THE PHASE ANGLE IS COMPARED WITH THE CURRENT
		588	; TABLE ENTRY AND ADJUSTED IF APPROPRIATE
		589	;
		590	DISPA: ;
0150	FB	591	MOV A, R3 ; CALC THE SUM OF PHASE ANGLE

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FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V. M-9.5					
LOC	OBJ	LINE	SOURCE STATEMENT		
0151	6C	592	ADD A, R4	AND DELAY (LOAD)	
0152	AD	593	MOV R5, A	SAVE IN R5: R5 FOR LATER	
0153	37	594	CPL A	IF THE SUM .GT. THAN THE	
0154	17	595	INC A	PRECALCULATED BOTTOM LIMIT	
0155	03E4	596	ADD A, #MINPT	OFFSET TABLE ENTRY	
0157	FD	597	MOV A, R5		
0158	47	598	SNAP A	UNLESS THE OFFSET IS ALREADY	
0159	530F	599	ANL A, #0FH	AT ZERO	
015B	F66A	600	JC PHBOK1	THE BOTTOM LIMIT HAS NOT BEEN EXCEEDED	
015D	0330	601	ADD A, #OFFTAB	OTHERWISE DECREMENT THE OFFSET	
015F	A8	602	MOV R0, A	POINT AT THE APPROPRIATE OFFSET TABLE	
0160	F0	603	MOV A, R0	LOAD THE ENTRY	
0161	530F	604	ANL A, #0FH	IF THE OFFSET IS ZERO THEN	
0163	C66D	605	JZ PHBOK	DON'T ADJUST	
0165	F0	606	MOV A, R0	ELSE DECREMENT BECAUSE THE TABLE	
0166	07	607	DEC A	IS TOO LOW	
0167	A0	608	MOV R0, A	REPLACE IN RAM	
0168	246D	609	JMP PHBOK	GO USE OFFSET	
016A	0330	610	PHBOK1: ADD A, #OFFTAB	USE THE CURRENT OFFSET TABLE	
016C	A8	612	MOV R0, A	RBO: R0=OFFTAB(SUM/16)	
016D	5400	613	PHBOK: CALL MODOFFS	GO MODIFY CALCULATED OFFSET	
016F	E3	615	MOV R3, A	A=SUMTAB(OFFTAB(SUM/16))	
0170	AD	616	MOV R5, A	SAVE OPTIMUM PHASE ANGLE	
		617			
		618		THIS IS THE HEART OF THE CONTROL ALGORITHM. HERE	
		619		THE BASIC SUMTAB IS USED TO DETERMINE THE OPTIMUM	
		620		PHASE ANGLE AND IT IS COMPARED TO THE CURRENT PHASE	
		621		ANGLE AND THE CURRENT DELAY IS MODIFIED ACCORDINGLY.	
		622			
0171	37	623	CPL A	COMPARE COUNT TO OPTIMUM	
0172	17	624	INC A	FROM THE TABLE + OFFSET	
0173	68	625	ADD A, R0	ADJUST OUTCOME WITH OFFSET	
0174	68	626	ADD A, R3	IF THE CURRENT PHASE ANGLE IS	
0175	C6B5	627	JZ PHASJ	EQUAL THE OPTIMUM THEN DO NOTHING	
0177	F6B7	628	JC CQTD	IF IT IS .GT. THEN ADD DELAY	
		629		ELSE DECREASE DELAY	
		630			
		631		HOWEVER THE DECREASED DELAY IS NOT IMPOSED IMMEDIATELY	
		632		IT IS DELAYED TO FORCE DAMPENING TO PREVENT OSCILLATIONS	
		633			
0179	BE1E	634	MOV R6, #HLDOFF	ELSE DECREASE DELAY	
017B	1F	635	INC R7	AND DELAY NEXT SAMPLE PERIOD	
017C	F7	636	RLC A	DOUBLE RECOVER ON LOADING	
017D	97	637	CLR C		
017E	F7	638	RLC A	DOUBLE AGAIN	
017F	6C	639	ADD A, R4		
0180	E60A	640	JNC DELO	TOO MUCH, USE 0 DELAY	
0182	C60A	641	JZ DELO		
0184	AC	642	MOV R4, A	SAVE UPDATED DELAY	
		643	PHASJ:		
0185	049B	644	JMP PHASE		
		645	CQTD:		
0187	97	646	CLR C	DIVIDE DIFF BY 2	

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FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V. M-9.5

LOC	OBJ	LINE	SOURCE STATEMENT
0188	67	647	RRC A
0189	C685	648	JZ PHASJ ; IF RESULT 0 THEN OK
018B	EE85	649	DJNZ R6, PHASJ ; IS IT OK TO UNLOAD
018D	BE01	650	MOV R6, #1 ; YES
018F	6C	651	ADD A, R4 ; INCREASE DELAY
0190	AC	652	MOV R4, A ; SAVE UPDATED DELAY
0191	049B	653	JMP PHASE
		654	;
		655	;
		656	*****
		657	*EJECT

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FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V.M-9.5

LOC	OBJ	LINE	SOURCE STATEMENT
		658	*****
		659	
		660	
		661	OFFSET SMOOTHING
		662	
		663	 THIS ROUTINE SMOOTHES THE OFFSET TABLE ACCORDING TO THE
		664	FOLLOWING ALGORITHM:
		665	ADJACENT POINTS ARE ADJUSTED SUCH THAT THE DIFFERENCE
		666	BETWEEN THEM IS EQUAL TO HALF THE DIFFERENCE IF THE
		667	ABSOLUTE DIFFERENCE WAS GREATER THAN 3
		668	
		669	SMOOTH:
0193	D5	673	SEL RB1 ; USE RB1 FOR NOW
		674	SM0:
0194	8834	675	MOV R0, #SMSTAD ; START ADDRESS FOR SMOOTHING
0196	BE0A	676	MOV R6, #SMNUMB ; MAXIMUM NUMBER OF ELEMENTS TO SMOOTH
		677	SM1:
0198	F0	678	MOV A, @R0 ; OFFTAB(I-1)
0199	530F	679	ANL A, #00001111B ; MASK OFF COUNT
019B	AB	680	MOV R3, A ; SAVE IN RB1:R3
019C	18	681	INC R0 ; I=I+1
019D	F0	682	MOV A, @R0 ; OFFTAB(I)
019E	530F	683	ANL A, #00001111B ; MASK OFF COUNT
01A0	AC	684	MOV R4, A ; SAVE IN RB1:R4
01A1	FB	685	MOV A, R3 ; OFFTAB(I-1)
01A2	C6AA	686	JZ SM2 ; SET FLAG FOR ADD OF ZERO
		687	NEG
		688+	MACRO V.M-1.0
01A4	37	689+	CPL A ; MAKE VALUE IN REG A
01A5	17	690+	INC A ; TWO'S COMPLIMENT
01A6	2C	691	XCH A, R4 ; A=OFFTAB(I)
01A7	6C	692	ADD A, R4 ; A=OFFTAB(I)-OFFTAB(I-1)
01A8	24AD	693	JMP SM3
		694	SM2:
01AA	FC	695	MOV A, R4 ; A=OFFTAB(I)
01AB	97	696	CLR C ; SET
01AC	A7	697	CPL C ; CARRY IF ADD OF ZERO
		698	SM3:
01AD	E6D9	699	JNC SM5 ; NEGATIVE DIFFERENCE
01AF	97	700	CLR C ; FORCE CARRY OFF
01B0	67	701	RRC A ; A=(OFFTAB(I)-OFFTAB(I-1))/2
01B1	1300	702	ADDC A, #0 ; ROUNDED
01B3	AD	703	MOV R5, A ; SAVE A IN RB1:R5
01B4	03FD	704	ADD A, #-3 ; IF A .EQ. .OR. .LT. 3 THEN IGNORE
01B6	F6BA	705	JC SM4 ; IT IS GT. SO PROCESS
01B8	24E9	706	JMP SMNXT ; ELSE IGNORE
		707	SM4:
01BA	C8	708	DEC R0 ; I=I-1
01BB	F0	709	MOV A, @R0 ; A=OFFTAB(I-1)
01BC	6D	710	ADD A, R5 ; A=OFFTAB(I-1)+
		711	((OFFTAB(I-1)-OFFTAB(I-1))/2
01BD	34C1	712	CALL FIXCNT ; GO FIXUP THE COUNT
01BF	2494	713	JMP SM0 ; GO START OVER
		714	
		715	 THE OFFSET HAS BEEN ADJUSTED NOW ADJUST THE COUNT

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FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V.M=9.5

LDC	OBJ	LINE	SOURCE STATEMENT
		716	TO EQUAL THE OFFSET LIMIT (10) LESS THE TOTAL
		717	SMOOTHED OFFSET
		718	
		719	FIXCNT:
01C1	530F	720	ANL A, #00001111B ; MASK OFF PREVIOUS COUNT
01C3	AD	721	MOV R5, A ; SAVE IN RB1:R5
		722	NEG
		723+	NEG MACRO V.M=1,0
01C4	37	724+	CPL A ; MAKE VALUE IN REG A
01C5	17	725+	INC A ; TWO'S COMPLIMENT
01C6	030A	726	ADD A, #MAXOFFS ; TOTAL MAXOFFSET - TOTAL OFFSET
01C8	47	727	SHAP A ; PUT DIFFERENCE IN UPPER NIBBLE
01C9	53F0	728	ANL A, #11110000B ; INSURE LBN ZERO
01CB	6D	729	ADD A, R5 ; ADD BACK OFFSET
01CC	A0	730	MOV @R0, A ; STORE IN OFFSET TABLE
		731	
		732	THE COUNT FIELD IN THE OFFSET TABLE IS NOW EQUAL TO THE
		733	DIFFERENCE BETWEEN THE TOTAL OFFSET AND THE MAXIMUM
		734	OFFSET
		735	
		736	NOW PLUS THE NEW OFFSET INTO THE CALLIN TABLE. NOTE THAT
		737	THIS CODE ASSUMES THAT THE CALLIN TABLE IS EXACTLY 16
		738	ADDRESSES LESS THAN THE OFFTAB
		739	
01CD	28	740	XCH A, R0 ; PUT THE ADDRESS IN RB1:R0
01CE	53EF	741	ANL A, #11101111B ; ADDRESS THE CALLIN
01D0	28	742	XCH A, R0 ; A AGAIN IS THE TOTAL OFFSET AND COUNT
01D1	530F	743	ANL A, #00001111B ; MASK OFF THE COUNT
01D3	A0	744	MOV @R0, A ; MAKE CALLIN
01D4	28	745	XCH A, R0 ; RETURN THE ADDRESS TO THE OFFTAB
01D5	4310	746	ORL A, #00010000B
01D7	28	747	XCH A, R0 ; AND RETURN IT TO RB1:R0
01D8	83	748	RET ; RETURN
		749	
		750	THE DIFFERENCE WAS NEGATIVE SO CALC WITH THE ABS(DIFF)
		751	
		752	SM5:
		753	NEG
		754+	NEG MACRO V.M=1,0
		755+	CPL A ; MAKE VALUE IN REG A
01D9	37	756+	INC A ; TWO'S COMPLIMENT
01DA	17	757	RRC A ; DIVIDE BY 2
01DB	67	758	ADDG A, #0 ; ROUND
01DC	1300	759	MOV R5, A ; SAVE IN RB1:R5
01DE	AD	760	ADD A, #-3 ; IF ABS(DIFF) .LT. .OR. .EQ. 3 IGNORE
01DF	03FD	761	JC SM6 ; ELSE IF .GT. -3 THEN PROCESS
01E1	F6E3	762	JMP SMNXT ; ELSE IGNORE
01E3	24E9	763	SM6:
		764	MOV A, @R0 ; A=OFFTAB(I)
01E5	F0	765	ADD A, R5 ; A=OFFTAB(I-1) +
01E6	6D	766	((OFFTAB(I)-OFFTAB(I-1))/2
01E7	04C1	767	CALL FIXCNT ; GO FIX THE COUNT
		768	SMNXT:
01E9	EE98	769	DJNZ R6, SM1 ; IF I>10 THEN DONE
		770	DONE:

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FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V. M-9.5

LOC	OBJ	LINE	SOURCE STATEMENT
01E8 C5		771	SEL R80
01EC 0498		775	JMP PHASE
		776	
		777	
		778	*****
		779	REJECT *****

RESET REGISTER BANK
GO BACK TO WAIT FOR VOLTAGE CROSSING

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FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V.M-9.9

LOC	OBJ	LINE	SOURCE STATEMENT
		780	*****
		781	
		782	CALIBRATION ROUTINES
		783	
		784	
01EE 440B		785	CAL1: JMP CAL1A ; JUMPS TO PAGE PAGE BOUNDARY
01F0 4416		786	CAL2: JMP CAL2A
01F2 442F		787	CAL3: JMP CAL3A
		788	
		789	FORCE CODE INTO NEXT PAGE
		790	
		791	FILL 200H
		792	FILL MACRO V.M-1.0
0200 00		810	DB 0 ; MEMORY FILLED TO THIS POINT WITH 00H
0200		811	ORG 200H
		812	MODDFB
0200 F0		813	MOV A, R0 ; LOAD LAST OFFSET
0201 530F		814	ANL A, #0FH
0203 AB		815	MOV R0, A ; SAVE OFFSET IN R0
0204 08		817	INS A, BUS ; LOAD SWITCHES
0205 5209		818	JNB MOD081 ; IF TRUE THEN USE OFFSETS
0207 8800		819	MOV R0, #0 ; ELSE FORCE OFFSET TO ZERO
		820	MOD081
0209 FD		822	MOV A, R5 ; ADJUST WITH OFFSET
020A B3		823	RET ; RETURN
		824	
		825	THIS IS THE FIRST PHASE OF CALIBRATION
		826	
		827	THIS ROUTINE IS ENTERED TO BEGIN THE CALIBRATION PROCESS
		828	THE CURRENT PHASE ANGLE IS SAVED IN R0:R2 FOR THE NEXT
		829	PHASE. THE DELAY COUNTER, R0:R4, IS INCREMENTED BY 20
		830	AND THE FLAGS ARE SET TO CAUSE THE NEXT ENTRY TO GO TO
		831	CAL2
		832	
		833	CAL1A:
0208 FB		834	MOV A, R3 ; SAVE ORIG PA
020C AA		835	MOV R2, A ; IN R0:R2
020D B5		836	CLR F0 ; SET CAL1 FLAG OFF
020E A5		837	CLR F1 ; AND
020F B5		838	CPL F1 ; SET CAL2 FLAG ON
0210 FC		839	MOV A, R4 ; LOAD CURRENT DELAY
0211 0314		840	ADD A, #20 ; AND ADD 20
0213 AC		841	MOV R4, A ; AND RESTORE TO R0:R4
0214 445E		842	JMP CAL4 ; NOW GO DELAY AND FILE
		843	
		844	THIS IS THE SECOND CALIBRATE PHASE
		845	
		846	THE DELAY HAS EXPIRED AND A NEW PHASE ANGLE HAS BEEN READ.
		847	THE CURRENT PHASE ANGLE IS SAVED IN R0:R5 AND R0:R6.
		848	THEN THE CURRENT PHASE ANGLE IS SUBTRACTED FROM THE INITIAL
		849	PHASE ANGLE SAVED JUST BEFORE THE IMPOSITION OF THE 20 COUNT
		850	DELAY. IF THE CURRENT PHASE ANGLE IS GREATER THAN THE PREVIOUS
		851	ONE THEN IT IS ASSUMED THAT THE CURRENT OFFSET (TABLE) IS TOO
		852	LOW & THE CALIBRATION PROCESS IS TERMINATED HERE WITH A BRANCH
		853	TO THE APPROPRIATE ADJUST ROUTINE.

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FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V.M-9.5

LOC	OBJ	LINE	SOURCE STATEMENT
		854	IF THE CURRENT PHASE ANGLE IS LESS THAN THE PREVIOUS THEN THE
		855	DIFFERENCE IS DIVIDED BY 3 AND SAVED IN R80:R6, THIS VALUE WILL
		856	BECOME THE THRESHOLD WHICH WILL DETERMINE IF THE TABLE
		857	SHOULD BE ADJUSTED. IE: $PT=P2+(P1-P2)/3$.
		858	
		859	CAL2A:
0216	A5	860	CLR F1 ; ADJUST THE FLAG TO FORCE CAL3
0217	95	861	CPL F0 ; SET 3RD CAL SECTION
0218	FB	862	MOV A, R3 ; LOAD CURRENT PHASE ANGLE
0219	AD	863	MOV R5, A ; ALSO SAVE IN R80:R5
021A	AE	864	MOV R6, A ; AND R80:R6
021B	37	865	CPL A ; SUBTRACT PREVIOUS
021C	17	866	INC A ; FROM CURRENT
021D	6A	867	ADD A, R2 ; AND CHECK FOR CURRENT .GT. PREV
021E	E666	868	JNC TOOLO ; IF SO THEN THIS POINT IS TOO LOW
		869	DIV3:
0220	03FD	870	ADD A, # -3 ; DIVIDE THE DIFFERENCE BY 3
0222	E627	871	JNC MOD3 ;
0224	1E	872	INC R6 ;
0225	4420	873	JMP DIV3 ;
		874	MOD3:
0227	37	875	CPL A ; AND ROUND
0228	962B	876	JNZ MOD30 ;
022A	1E	877	INC R6 ;
		878	MOD30:
022B	8F05	879	MOV R7, #CALCYC ; SET NUMBER OF CYCLES TO LOOK FOR
022D	445E	880	JMP CAL4 ; RECOVERY
		881	
		882	THE LAST PHASE OF CALIBRATION MONITORS THE NEXT 'N' CYCLES
		883	AND LOOKS FOR THE PHASE ANGLE TO EXCEED THE THRESHOLD. IF
		884	IT DOES THEN THE CURRENT OFFSET IS TOO LOW SO THE OFFSET
		885	IN THIS REGION IS EFFECTIVELY DECREASED NETTING A HIGHER
		886	OR SAFER TABLE. IF THE RESULTING PHASE ANGLE STAYED BELOW
		887	THE THRESHOLD THEN THE OFFSET IS INCREASED EFFECTING A LOWER
		888	TABLE WHICH WILL RESULT IN GREATER ENERGY SAVINGS.
		889	THIS SECTION ALSO MONITORS THE PHASE ANGLE FOR A MARKED
		890	DECREASE. IF THE PHASE ANGLE DECREASES FROM THE INITIAL
		891	PHASE ANGLE AFTER THE STEP DELAY BY MORE THAN TWO THEN
		892	IT IS ASSUMED THAT THE MOTOR IS BEING LOADED SO THE PROGRAM
		893	BEATS A HASTY RETREAT AND EXITS THE CALIBRATION EARLY.
		894	
		895	CAL3A:
022F	EF3F	896	DJNZ R7, CAL5 ; SEE IF CAL PERIOD UP
0231	882F	897	MOV R0, #OFFPT ; SINCE PA HELD, PULL TABLE DOWN
0233	F0	898	A, #R0 ; INC OFFSET IF NOT 15
0234	AB	899	MOV R0, A ;
0235	F0	900	MOV A, #R0 ;
0236	530F	901	ANL A, #QFH ;
0238	03F6	902	ADD A, #QFSLIM ; INSURE NO OFFSET CALCULATED OVER 10
023A	C655	903	JZ CALEX1 ; IF SO EXIT HERE
023C	10	904	INC #R0 ; ELSE INCREMENT OFFSET
023D	4455	905	JMP CALEX2 ; THEN GET OUT
		906	CAL5:
023F	FD	907	MOV A, R5 ; SEE IF PHASE ANGLE WENT ANY LOWER
		908	NEQ

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FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V.M=9.5

LOC	OBJ	LINE	SOURCE STATEMENT
		909+	NEO MACRO V.M=1.0
0240	37	910+	CPL A ; MAKE VALUE IN REG A
0241	17	911+	INC A ; TWO'S COMPLIMENT
0242	68	912	ADD A, R3
0243	F64D	913	JC SAME ; NO, GO ON
0245	17	914	INC A ; SEE IF LOWER BY ONLY 1
0246	C64D	915	JZ SAME ; YES, IGNORE AND GO ON
0248	17	916	INC A ; SEE IF LOWER BY ONLY 2
0249	C64D	917	JZ SAME ; YES, IGNORE AND GO ON
0248	4455	918	JMP CALEX3 ; NO, ASSUME MOTOR BEING LOADED
		919	SAME:
024D	FE	920	MOV A, R6 ; SEE IF PN > PT
024E	37	921	CPL A ; SUBTRACT AND
024F	17	922	INC A ; COMPARE
0250	68	923	ADD A, R3
0251	E65E	924	JNC CAL4 ; NO CONTINUE
0253	4466	925	JMP TOOLO ; YES THE CURRENT OFFSET IS TOO LOW
		926	CALEX1:
		932	CALEX2:
		938	CALEX3:
		944	CALEX4:
		950	CALEX:
0255	B5	951	CLR F0 ; YES, NO CHANGE, TURN OFF 3RD CAL SEC:
0256	BF3C	952	MOV R7, #INTVLC ; END CAL PERIOD
0258	FC	953	MOV A, R4 ; RESTORE DELAY
0259	03EC	954	ADD A, #-20 ; TO IT'S VALUE UPON ENTRY
025B	AC	955	MOV R4, A
025C	243E	956	JMP DELAY ; GET OUT
		957	;
		958	CAL4:
		959	DELY1:
025E	1662	960	JTF FIRE1 ; WAIT FOR DELAY TO EXPIRED
0260	445E	961	JMP DELY1
		962	FIRE1:
0262	8A0B	963	ORL P2, #TRON ; TURN ON TRIAC
0264	049B	964	JMP PHASE
		965	;
		966	;
		967	THE PHASE ANGLE CONTINUED TO DROOP SO IT IS ASSUMED
		968	THAT THE CURRENT TABLE IS TOO LOW AND WE INCREMENT
		969	THE OFFSET
		970	TOOLO:
0266	B82F	971	MOV R0, #OFFPT ; LOAD R0: R0 WITH ADDRESS OF OFFPT
0268	F0	972	MOV A, @R0 ; LOAD A WITH ADDRESS OF OFFTAB(CALPT)
0269	A8	973	MOV R0, A ; PUT THE CURRENT OFFTAB(CALPT) IN R0
026A	F0	974	MOV A, @R0 ; NOW INTO A
026B	530F	975	ANL A, #OFH ; MASK OFF CALIBRATION COUNT
026D	C655	976	JZ CALEX ; IF OFFSET ALREADY ZERO DON'T ADJUST
026F	28	977	XCH A, R0 ; PUT ADDRESS OF OFFTAB(CALPT) INTO A
		978	;
		979	;
		980	THIS NEXT SECTION ASSUMES THAT THE ADDRESS OF THE CALLIM
		981	TABLE IS EXACTLY 16 LESS THAN THE ADDRESS OF THE OFFTAB
		982	ADDRESS WHERE THE CALIBRATION STARTS. IF IT IS NOT THE
		983	RESULTS ARE UNPREDICATABLE

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FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V. M-9.5

LOC	OBJ	LINE	SOURCE STATEMENT
0270	53EF	984	ANL A, #1101111B ; MODIFY THE ADDRESS
0272	28	985	XCH A, RO ; PUT THE MODIFIED ADDRESS INTO RO
		986	
		987	NEQ ; AND THE CURRENT OFFSET IS IN A
0273	37	988+1	NEQ MACRO V, M=1.0 ; MAKE VALUE IN REG A
0274	17	989+	CPL A ; TWO'S COMPLIMENT
0275	60	990+	INC A ; COMPARE THE CURRENT OFFSET AND LIMIT
0276	E67A	991	ADD A, RO ; IF CURRENT OFFSET GT. LIMIT ADJUST
0278	4459	992	JNC ADJOS ; ELSE DO NOT ADJUST THE OFFSET
		993	JMP CALEX
		994	ADJOS
027A	28	995	XCH A, RO ; PUT CALLIM(CALPT) ADDRESS INTO A
027B	4310	996	ORL A, #00010000B ; MAKE OFFTAB(CALPT)
027D	F0	997	MOV A, RO ; LOAD OFFSET
027E	07	998	DEC A ; ADJUST DOWN OR LESS OF AN OFFSET
027F	A0	999	MOV A, RO, A ; RESTORE INTO TABLE
0280	4455	1000	JMP CALEX4 ; EXIT
		1001	
		1002	
		1003	*** *****
		1004	SEJEC *****

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FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V. M-9.5

LOC	OBJ	LINE	SOURCE STATEMENT
		1005 ; *****	
		1006 ;	
		1007 ;	INTERRUPT HANDLERS
		1008 ;	
		1009 ;	
		1010 TINT:	
0292	93	1011	RETR RETURN
		1012 EXTI:	
0293	93	1013	RETR
		1014 ;	
		1015 ;	
		1016 ; *****	
		1017 EJECT:	

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FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V.M=9.5

LOC	OBJ	LINE	SOURCE STATEMENT
		1018	*****
		1019	
		1020	BASIC OPERATING TABLE
		1021	
		1022	 THIS TABLE CONTAINS THE OPERATING PHASE ANGLES BASED ON
		1023	THE SUM OF THE MEASURED PHASE ANGLE AND THE DELAY FOUND
		1024	WHICH WILL GENERATE THAT PHASE ANGLE. THE PHASE ANGLES
		1025	ARE LOOKED UP IN THIS TABLE BY ADDING THE MEASURED PHASE
		1026	ANGLE TO THE GENERATED DELAY AND OFFSETTING THE BASE
		1027	ADDRESS TO POINT TO THE PROPER ENTRY.
		1028	
		1029	FILL 300H
		1030	FILL MACRO V.M=1.0
0300	00	1160	DB 0 / MEMORY FILLED TO THIS POINT WITH 00H
0300		1161	ORG 300H
		1162	*INCLUDE(=FO: AUTOTS.SRC)
		1163	Auto calibrate control table
		1164	
		1165	M= 12
		1166	B= 70
		1167	
		1168	MAXDLY= 180
		1169	MINPT= 228.4
		1170	MAXPT= 70.88
		1171	
00E4		1172	MINPT EQU 228
0047		1173	MAXPT EQU 71
0300	64	1174	db 100 / offset: 1
0301	64	1175	db 100 / offset: 2
0302	64	1176	db 100 / offset: 3
0303	64	1177	db 100 / offset: 4
0304	64	1178	db 100 / offset: 5
0305	64	1179	db 100 / offset: 6
0306	64	1180	db 100 / offset: 7
0307	64	1181	db 100 / offset: 8
0308	64	1182	db 100 / offset: 9
0309	64	1183	db 100 / offset: 10
030A	64	1184	db 100 / offset: 11
030B	64	1185	db 100 / offset: 12
030C	64	1186	db 100 / offset: 13
030D	64	1187	db 100 / offset: 14
030E	64	1188	db 100 / offset: 15
030F	64	1189	db 100 / offset: 16
0310	64	1190	db 100 / offset: 17
0311	64	1191	db 100 / offset: 18
0312	64	1192	db 100 / offset: 19
0313	64	1193	db 100 / offset: 20
0314	64	1194	db 100 / offset: 21
0315	64	1195	db 100 / offset: 22
0316	64	1196	db 100 / offset: 23
0317	64	1197	db 100 / offset: 24
0318	64	1198	db 100 / offset: 25
0319	64	1199	db 100 / offset: 26
031A	64	1200	db 100 / offset: 27
031B	64	1201	db 100 / offset: 28

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FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V.M=9.5

LOC	OBJ	LINE	SOURCE STATEMENT		
031C	64	=1202	db	100	:offset: 29
031D	64	=1203	db	100	:offset: 30
031E	64	=1204	db	100	:offset: 31
031F	64	=1205	db	100	:offset: 32
0320	64	=1206	db	100	:offset: 33
0321	64	=1207	db	100	:offset: 34
0322	64	=1208	db	100	:offset: 35
0323	64	=1209	db	100	:offset: 36
0324	64	=1210	db	100	:offset: 37
0325	64	=1211	db	100	:offset: 38
0326	64	=1212	db	100	:offset: 39
0327	64	=1213	db	100	:offset: 40
0328	64	=1214	db	100	:offset: 41
0329	64	=1215	db	100	:offset: 42
032A	64	=1216	db	100	:offset: 43
032B	64	=1217	db	100	:offset: 44
032C	64	=1218	db	100	:offset: 45
032D	64	=1219	db	100	:offset: 46
032E	64	=1220	db	100	:offset: 47
032F	64	=1221	db	100	:offset: 48
0330	64	=1222	db	100	:offset: 49
0331	64	=1223	db	100	:offset: 50
0332	64	=1224	db	100	:offset: 51
0333	64	=1225	db	100	:offset: 52
0334	64	=1226	db	100	:offset: 53
0335	64	=1227	db	100	:offset: 54
0336	64	=1228	db	100	:offset: 55
0337	64	=1229	db	100	:offset: 56
0338	64	=1230	db	100	:offset: 57
0339	64	=1231	db	100	:offset: 58
033A	64	=1232	db	100	:offset: 59
033B	64	=1233	db	100	:offset: 60
033C	64	=1234	db	100	:offset: 61
033D	64	=1235	db	100	:offset: 62
033E	64	=1236	db	100	:offset: 63
033F	64	=1237	db	100	:offset: 64
0340	64	=1238	db	100	:offset: 65
0341	64	=1239	db	100	:offset: 66
0342	64	=1240	db	100	:offset: 67
0343	64	=1241	db	100	:offset: 68
0344	64	=1242	db	100	:offset: 69
0345	64	=1243	db	100	:offset: 70
0346	45	=1244	db	69	:offset: 71
0347	45	=1245	db	69	:offset: 72
0348	45	=1246	db	69	:offset: 73
0349	45	=1247	db	69	:offset: 74
034A	45	=1248	db	69	:offset: 75
034B	45	=1249	db	69	:offset: 76
034C	45	=1250	db	69	:offset: 77
034D	44	=1251	db	68	:offset: 78
034E	44	=1252	db	68	:offset: 79
034F	44	=1253	db	68	:offset: 80
0350	44	=1254	db	68	:offset: 81
0351	44	=1255	db	68	:offset: 82
0352	44	=1256	db	68	:offset: 83

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FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V.M-9.5

LOC	OBJ	LINE	SOURCE STATEMENT		
0353	44	=1257	db	68	offset: 84
0354	43	=1258	db	67	offset: 85
0355	43	=1259	db	67	offset: 86
0356	43	=1260	db	67	offset: 87
0357	43	=1261	db	67	offset: 88
0358	43	=1262	db	67	offset: 89
0359	43	=1263	db	67	offset: 90
035A	43	=1264	db	67	offset: 91
035B	43	=1265	db	67	offset: 92
035C	42	=1266	db	66	offset: 93
035D	42	=1267	db	66	offset: 94
035E	42	=1268	db	66	offset: 95
035F	42	=1269	db	66	offset: 96
0360	42	=1270	db	66	offset: 97
0361	42	=1271	db	66	offset: 98
0362	42	=1272	db	66	offset: 99
0363	41	=1273	db	65	offset: 100
0364	41	=1274	db	65	offset: 101
0365	41	=1275	db	65	offset: 102
0366	41	=1276	db	65	offset: 103
0367	41	=1277	db	65	offset: 104
0368	41	=1278	db	65	offset: 105
0369	41	=1279	db	65	offset: 106
036A	40	=1280	db	64	offset: 107
036B	40	=1281	db	64	offset: 108
036C	40	=1282	db	64	offset: 109
036D	40	=1283	db	64	offset: 110
036E	40	=1284	db	64	offset: 111
036F	40	=1285	db	64	offset: 112
0370	40	=1286	db	64	offset: 113
0371	40	=1287	db	64	offset: 114
0372	3F	=1288	db	63	offset: 115
0373	3F	=1289	db	63	offset: 116
0374	3F	=1290	db	63	offset: 117
0375	3F	=1291	db	63	offset: 118
0376	3F	=1292	db	63	offset: 119
0377	3F	=1293	db	63	offset: 120
0378	3F	=1294	db	63	offset: 121
0379	3E	=1295	db	62	offset: 122
037A	3E	=1296	db	62	offset: 123
037B	3E	=1297	db	62	offset: 124
037C	3E	=1298	db	62	offset: 125
037D	3E	=1299	db	62	offset: 126
037E	3E	=1300	db	62	offset: 127
037F	3E	=1301	db	62	offset: 128
0380	3D	=1302	db	61	offset: 129
0381	3D	=1303	db	61	offset: 130
0382	3D	=1304	db	61	offset: 131
0383	3D	=1305	db	61	offset: 132
0384	3D	=1306	db	61	offset: 133
0385	3D	=1307	db	61	offset: 134
0386	3D	=1308	db	61	offset: 135
0387	3D	=1309	db	61	offset: 136
0388	3C	=1310	db	60	offset: 137
0389	3C	=1311	db	60	offset: 138

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FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V. M-9.5

LOC	OBJ	LINE	SOURCE STATEMENT
038A	3C	=1312	db 60 ;offset: 139
038B	3C	=1313	db 60 ;offset: 140
038C	3C	=1314	db 60 ;offset: 141
038D	3C	=1315	db 60 ;offset: 142
038E	3C	=1316	db 60 ;offset: 143
038F	3B	=1317	db 59 ;offset: 144
0390	3B	=1318	db 59 ;offset: 145
0391	3B	=1319	db 59 ;offset: 146
0392	3B	=1320	db 59 ;offset: 147
0393	3B	=1321	db 59 ;offset: 148
0394	3B	=1322	db 59 ;offset: 149
0395	3B	=1323	db 59 ;offset: 150
0396	3A	=1324	db 58 ;offset: 151
0397	3A	=1325	db 58 ;offset: 152
0398	3A	=1326	db 58 ;offset: 153
0399	3A	=1327	db 58 ;offset: 154
039A	3A	=1328	db 58 ;offset: 155
039B	3A	=1329	db 58 ;offset: 156
039C	3A	=1330	db 58 ;offset: 157
039D	3A	=1331	db 58 ;offset: 158
039E	37	=1332	db 57 ;offset: 159
039F	37	=1333	db 57 ;offset: 160
03A0	37	=1334	db 57 ;offset: 161
03A1	37	=1335	db 57 ;offset: 162
03A2	37	=1336	db 57 ;offset: 163
03A3	37	=1337	db 57 ;offset: 164
03A4	37	=1338	db 57 ;offset: 165
03A5	36	=1339	db 56 ;offset: 166
03A6	36	=1340	db 56 ;offset: 167
03A7	36	=1341	db 56 ;offset: 168
03A8	36	=1342	db 56 ;offset: 169
03A9	36	=1343	db 56 ;offset: 170
03AA	36	=1344	db 56 ;offset: 171
03AB	36	=1345	db 56 ;offset: 172
03AC	37	=1346	db 55 ;offset: 173
03AD	37	=1347	db 55 ;offset: 174
03AE	37	=1348	db 55 ;offset: 175
03AF	37	=1349	db 55 ;offset: 176
03B0	37	=1350	db 55 ;offset: 177
03B1	37	=1351	db 55 ;offset: 178
03B2	37	=1352	db 55 ;offset: 179
03B3	37	=1353	db 55 ;offset: 180
03B4	36	=1354	db 54 ;offset: 181
03B5	36	=1355	db 54 ;offset: 182
03B6	36	=1356	db 54 ;offset: 183
03B7	36	=1357	db 54 ;offset: 184
03B8	36	=1358	db 54 ;offset: 185
03B9	36	=1359	db 54 ;offset: 186
03BA	36	=1360	db 54 ;offset: 187
03BB	35	=1361	db 53 ;offset: 188
03BC	35	=1362	db 53 ;offset: 189
03BD	35	=1363	db 53 ;offset: 190
03BE	35	=1364	db 53 ;offset: 191
03BF	35	=1365	db 53 ;offset: 192
03C0	35	=1366	db 53 ;offset: 193

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FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V.M-9.5

LOC	OBJ	LINE	SOURCE STATEMENT
03C1	35	=1367	db 53 ; offset: 194
03C2	34	=1368	db 52 ; offset: 195
03C3	34	=1369	db 52 ; offset: 196
03C4	34	=1370	db 52 ; offset: 197
03C5	34	=1371	db 52 ; offset: 198
03C6	34	=1372	db 52 ; offset: 199
03C7	34	=1373	db 52 ; offset: 200
03C8	34	=1374	db 52 ; offset: 201
03C9	34	=1375	db 52 ; offset: 202
03CA	33	=1376	db 51 ; offset: 203
03CB	33	=1377	db 51 ; offset: 204
03CC	33	=1378	db 51 ; offset: 205
03CD	33	=1379	db 51 ; offset: 206
03CE	33	=1380	db 51 ; offset: 207
03CF	33	=1381	db 51 ; offset: 208
03D0	33	=1382	db 51 ; offset: 209
03D1	32	=1383	db 50 ; offset: 210
03D2	32	=1384	db 50 ; offset: 211
03D3	32	=1385	db 50 ; offset: 212
03D4	32	=1386	db 50 ; offset: 213
03D5	32	=1387	db 50 ; offset: 214
03D6	32	=1388	db 50 ; offset: 215
03D7	32	=1389	db 50 ; offset: 216
03D8	31	=1390	db 49 ; offset: 217
03D9	31	=1391	db 49 ; offset: 218
03DA	31	=1392	db 49 ; offset: 219
03DB	31	=1393	db 49 ; offset: 220
03DC	31	=1394	db 49 ; offset: 221
03DD	31	=1395	db 49 ; offset: 222
03DE	31	=1396	db 49 ; offset: 223
03DF	31	=1397	db 49 ; offset: 224
03E0	30	=1398	db 48 ; offset: 225
03E1	30	=1399	db 48 ; offset: 226
03E2	30	=1400	db 48 ; offset: 227
03E3	30	=1401	db 48 ; offset: 228
03E4	30	=1402	db 48 ; offset: 229
03E5	30	=1403	db 48 ; offset: 230
03E6	30	=1404	db 48 ; offset: 231
03E7	30	=1405	db 48 ; offset: 232
03E8	30	=1406	db 48 ; offset: 233
03E9	30	=1407	db 48 ; offset: 234
03EA	30	=1408	db 48 ; offset: 235
03EB	30	=1409	db 48 ; offset: 236
03EC	30	=1410	db 48 ; offset: 237
03ED	30	=1411	db 48 ; offset: 238
03EE	30	=1412	db 48 ; offset: 239
03EF	30	=1413	db 48 ; offset: 240
03F0	30	=1414	db 48 ; offset: 241
03F1	30	=1415	db 48 ; offset: 242
03F2	30	=1416	db 48 ; offset: 243
03F3	30	=1417	db 48 ; offset: 244
03F4	30	=1418	db 48 ; offset: 245
03F5	30	=1419	db 48 ; offset: 246
03F6	30	=1420	db 48 ; offset: 247
03F7	30	=1421	db 48 ; offset: 248

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FULLY AUTOMATIC SINGLE-PHASE DIGITAL MOTOR CONTROLLER V.M-9.5

LOC OBJ LINE SOURCE STATEMENT

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03F8 30 -1422 db 48 offset: 249
03F9 30 -1423 db 48 offset: 250
03FA 30 -1424 db 48 offset: 251
03FB 30 -1425 db 48 offset: 252
03FC 30 -1426 db 48 offset: 253
03FD 30 -1427 db 48 offset: 254
03FE 30 -1428 db 48 offset: 255
03FF 00 -1429 db 0 offset: 256
1430 END

```

USER SYMBOLS

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ADJ08 027A BEGRAM 0020 CAL1 01EE CAL1A 0208 CAL2 01F0 CAL2A 0216 CAL3 01F2 CAL3A 022F
CAL4 025E CAL5 023F CAL6 0255 CALEX 0112 DBNCE 00A4 DEBU9 0000 CALEX2 0255 CALEX3 0255 CALEX4 0255
CALLIM 0024 COTO 0187 CLEAR1 004B CUROX 0112 DBNCE 00A4 DEBU9 0000 CALEX2 0255 CALEX3 0255 CALEX4 0255
DELY1 025E DEMO FFFF DISPA 0150 DIV3 0220 DONE 01EB ENDRAM 003F FULLP1 0096 MAXHT 0006 NEG 0001 OFFPT 002F OFFTAB 0030
FILL 0000 FIRE 0142 FIRE1 0242 FIXCNT 01C1 FULLP 0094 MAXHT 0047 MSTOP 00B1 PHSDK1 016A PHSDK2 016B PHSDK3 016C
INTVLC 003C IP2 003B JPPH8 014E JPPH9 014F JPPH0 0150 JPPH1 0151 JPPH2 0152 JPPH3 0153 JPPH4 0154 JPPH5 0155
MOD30 022B MOD0FB 0200 MOD0S1 0209 MOD0S2 020A MOD0S3 020B MOD0S4 020C MOD0S5 020D MOD0S6 020E MOD0S7 020F
OFSLIM FFF6 PHASE 0098 PHASJ 0188 PHSDK 016D PHSDK1 016A PHSDK2 016B PHSDK3 016C PHSDK4 016D PHSDK5 016E
SM2 01AA SM3 01AD SM4 01AE SM5 01D9 SM6 01D9 SM7 01D9 SM8 01D9 SM9 01D9 SM10 01D9 SM11 01D9 SM12 01D9
SMSTAD 0034 TINT 0282 TODLD 0265 TR0FF 00F7 TRON 0008 TRUE 000A TRUE 000A TRUE 000A TRUE 000A TRUE 000A TRUE 000A
WAITC 0104 WAITP 0109

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ASSEMBLY COMPLETE. NO ERRORS

PAGE 1

ADJOB	992	994#																		
BEOGRAM	134#	241	242																	
CAL1	561	785#																		
CAL1A	785	833#																		
CAL2	534	786#																		
CAL2A	786	859#																		
CAL3	533	787#																		
CAL3A	787	895#																		
CAL4	842	880	924	958#																
CAL5	896	906#																		
CALCYC	125#	879																		
CALEX	950#	976	993																	
CALEX1	903	926#																		
CALEX2	905	932#																		
CALEX3	918	938#																		
CALEX4	944#	1000																		
CALLIM	148#																			
COTG	628	645#																		
CLEAR1	243#	246																		
CUROX	490	511#																		
DBNCE	362#	366																		
DEBUO	28#	136	217	299	492	500	670	772	927	933	939	945								
DELO	499#	640	641																	
DELAY	532	537	554	565#	567	936														
DELY1	959#	961																		
DEMO	27#	29	212	312	348	816														
DISPA	572	590#																		
DIV3	869#	873																		
DONE	770#																			
ENDRAM	152#	242																		
EXTI	190	1012#																		
FALSE	25#	28																		
FILL	59#	388	791	1029																
FIRE	566	568#																		
FIRE1	960	962#																		
FIXCNT	712	719#	767																	
FULLP	329#	352																		
FULLP1	331#	334																		
HLDOFF	120#	232	634																	
INIT	188	208#	323	333																
INTVLC	124#	237	540	932																
IP2	116#	220																		
JMPPHS	575	576	581#																	
MAXOF8	122#	265	267	269	271	273	275	277	279	281	283	285	726							
MAXPT	1173#																			
MAXWT	119#	477																		
MINPT	596	1172#																		
MOD3	871	874#																		
MOD30	876	878#																		
MODOF8	614	812#																		
MODOS1	818	820#																		
MSTOP	215	319#	351																	
MSTOP1	321#	324																		
NEO	68#	519	687	722	753	908	987													
OFFPT	149#	548	897	971																
OFFTAB	150#	151	254	547	601	611														
OFSLIM	123#	902																		

ISIS-II ASSEMBLER SYMBOL CROSS REFERENCE V2.1

PAGE 2

PHASE	313	347#	365	507	582	644	653	779	964
PHASJ	627	643#	648	649					
PHSOK	605	609	613#						
PHBOK1	600	610#							
SAME	913	915	917	919#					
SM0	674#	713							
SM1	677#	769							
SM2	686	694#							
SM3	693	698#							
SM4	705	707#							
SM5	699	752#							
SM6	761	763#							
SMNUMB	126#	676							
SMNXT	706	762	768#						
SMOOTH	577	669#							
SMSTAD	151#	675							
TINT	192	1010#							
TOOLO	868	925	970#						
TROFF	117#	320	380						
TRON	118#	330	505	569	963				
TRUE	24#	27							
VLTDEN	121#	355							
WAIT	291#	292	293	294					
WAITC	487#	491							
WAITP	384	475#	476						

CROSS REFERENCE COMPLETE



CLAIMS:

1. A method for operating an induction motor control system comprising the steps of:
 - (a) energizing an induction motor using a firing delay;
 - (b) measuring the phase angle between motor voltage and
5 current zero crossings;
 - (c) determining a phase angle in accordance with the equation $y = mx + b$, where y is the phase angle, m is the slope, x is the firing delay and b is the offset, m and b being predetermined constants;
 - 10 (d) comparing the measured phase angle with the determined phase angle; and
 - (e) altering the firing delay based on the comparison to reduce the difference between the measured and determined phase angles.
2. A method according to Claim 1 wherein the amount by which
15 said firing delay is altered is proportional to the difference between the measured and determined phase angles.
3. A method according to Claim 2 wherein said firing delay is increased by an amount equal to one half the difference between the measured and determined phase angles.
- 20 4. A method according to Claim 2 wherein said firing delay is decreased by an amount equal to four times the difference between the measured and determined phase angles.
5. A method for operating an induction motor control system comprising the steps of:
 - 25 (a) energizing an induction motor using a firing delay;



- (b) measuring the phase angle between motor voltage and current zero crossings;
- (c) determining a phase angle in accordance with the equation $y = mx + b$, where y is the phase angle, m is the slope, x is the firing delay and b is the offset, m and b being predetermined constants;
- (d) comparing the measured phase angle with the determined phase angle;
- (e) increasing the firing delay based on the comparison to reduce the difference between the measured and determined phase angles; and
- (f) repeating steps (a) through (e) until the determined phase angle and the measured phase angle are approximately equal.
6. A method according to any of Claims 1-5 wherein m is negative.
7. A method according to Claim 6 wherein m is between about - 0.1 and about - 0.2.
8. A method according to any of Claims 1-5 wherein m is positive.
9. A method according to Claim 8 wherein m is between about 0.5 and about 0.7.
10. A method according to any of Claims 1-5 wherein m is negative and b is between about 65 and about 72 electrical degrees.
11. A method according to any of Claims 1-5 wherein m is positive and b is between about 10 and about 30 electrical degrees.



12. A digital method for operating an induction motor control system comprising the steps of:
 - (a) energizing an induction motor using a firing delay;
 - (b) measuring the phase angle between motor voltage and
5 current zero crossings;
 - (c) computing the sum of the measured phase angle and the firing delay;
 - (d) using said sum to determine a phase angle generated in accordance with the equation $y=mx + b$, where y is the phase
10 angle, m is the slope, x is the firing delay and b is the offset, m and b being predetermined constants;
 - (e) comparing the measured phase angle with the determined phase angle; and
 - (f) altering the firing delay based on the comparison to
15 reduce the difference between the measured and determined phase angles.
13. A digital method for operating an AC induction motor control system comprising the steps of:
 - (a) energizing an induction motor using a firing delay;
 - 20 (b) measuring the phase angle between motor voltage and current zero crossings;
 - (c) computing the sum of the measured phase angle and the firing delay;
 - (d) using said sum to determine a phase angle generated in
25 accordance with the equation $y=mx + b$, where y is the phase angle, m is the slope, x is the firing delay and b is the offset, m and b being predetermined constants;



- (e) comparing the measured phase angle with the determined phase angle;
- (f) increasing the firing delay based on the comparison to reduce the difference between the measured and determined phase angles;
- 5 (g) repeating steps (a) through (f) until the measured phase angle and the determined phase angle are approximately equal.
14. A method according to Claim 13 comprising the additional steps of:
- (a) measuring and storing an initial phase angle at time T_0 ;
- 10 (b) increasing the firing delay by a predetermined amount;
- (c) measuring and storing the resulting phase angle at times T_1 , $T_2 \dots T_n$;
- (d) comparing said initial phase angle with the resulting phase angles; and
- 15 (e) altering said firing delay based on said comparisons.
15. A method according to Claim 14 wherein the phase angle at T_n is less than the phase angle at T_1 and said firing delay is reduced.
16. A method according to Claim 14 wherein the difference between
- 20 the phase angle at T_n and the phase angle at T_1 is less than one third of the difference between the phase angle at T_0 and the phase angle at T_1 and said firing delay is reduced.
17. A method according to Claim 14 wherein the difference between
- 25 the phase angle at T_n and the phase angle at T_1 is greater than one third of the difference between the phase angle at T_0 and the phase angle at T_1 and the firing delay is increased.



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18. A method according to Claim 17 wherein said firing delay is increased by decrementing the offset.
19. A method according to any of Claims 12-18 wherein m is negative.
- 5 20. A method according to Claim 19 wherein m is between about - 0.1 and about - 0.2.
21. A method according to any of Claims 12-18 wherein m is positive.
22. A method according to Claim 21 wherein m is between about
- 10 0.5 and about 0.7.
23. A method according to any of Claims 12-18 wherein m is negative and b is between about 65 and about 72 electrical degrees.
24. A method according to any of Claims 12-18 wherein m is positive and b is between about 10 and about 30 electrical degrees.

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