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AN2149

Compressor Induction Motor Stall and Rotation Detection using Microcontrollers

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1 Introduction

Domestic refrigeration appliances commonly use single-phase induction motors to drive a compressor pump. The compressor is used to provide and maintain the required refrigerant pressure to allow the fridge compartment to function within the desired pre-selected temperature range. This application note provides a method of detecting a motor stall condition and a means for monitoring rotation during normal run conditions. Motor stall/rotation detection is based on a phase difference measurement between the run and start windings of the motor. This is achieved very conveniently using the timer input capture features available on the Motorola HC908KX8 low cost high performance 'flash' Microcontroller.

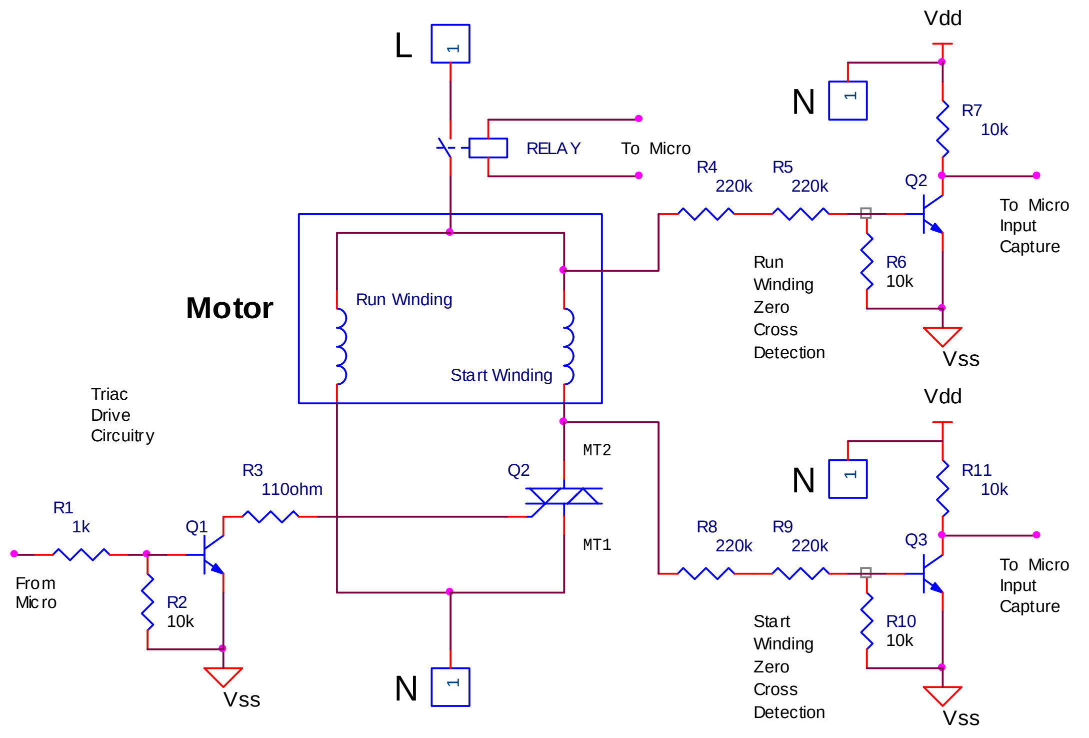
There is a necessity to provide some form of protection from conditions that may cause the motor windings to sustain thermal damage during start-up. This can be caused by a motor stall condition. If the motor is stalled, overheating will occur fairly rapidly and may cause permanent damage to the Motor windings. For example, mechanical failure of the compressor pump may impair the rotation of the motor and result in a stall condition.

Compressor motors in today’s refrigeration appliances are thermally protected by a bi-metallic contact that is embedded in the motor windings. This contact is in series with the AC line supply to the motor and will open and remove power to the motor when overheating occurs, for example, due to a motor stall condition. This method is suitable only for providing thermal protection of the motor windings. From power-on this can be achieved more efficiently and economically using a Motorola Microcontroller Embedded Solution. The Microcontroller solution has the additional advantage of providing a method of stall detection by detecting the rotation of the motor at start-up and monitoring rotation during normal run conditions.

2 AC Line Zero Cross Detection Hardware

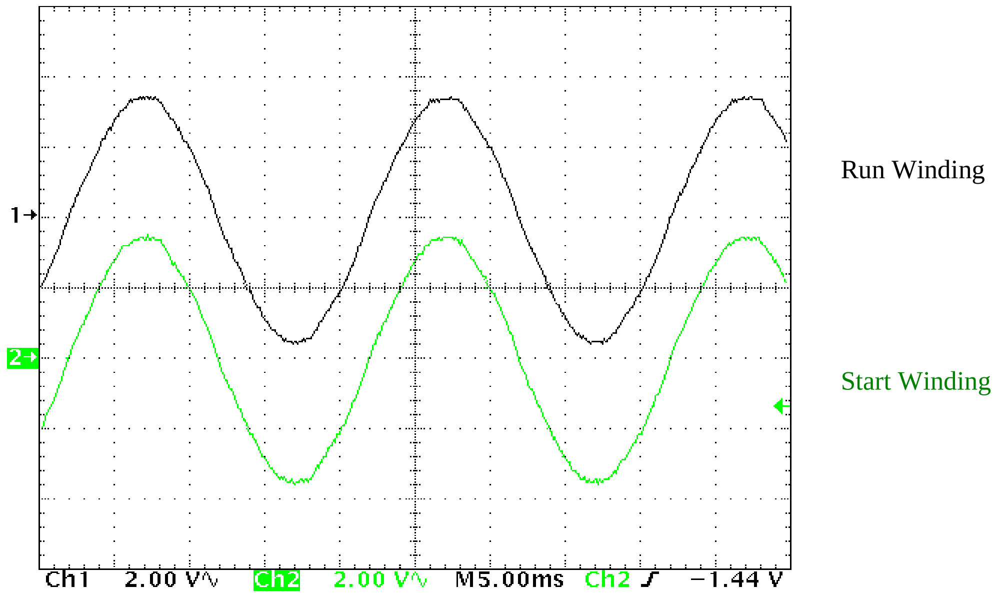
Implementing an efficient motor start procedure can be achieved using a Triac and relay control technique. This involves firstly applying power to the run winding of the motor using the Relay. The Triac is connected in series with the start winding and is fired close to the zero crossing points of the line voltage for a specific period of time to start the motor. After this period the Triac is turned off and the motor continues to run. The start winding provides the initial starting torque and, after the motor has started, it has no further duty until the motor is powered down and re-started. A schematic diagram of the hardware required follows.

2.1 Detection Schematic



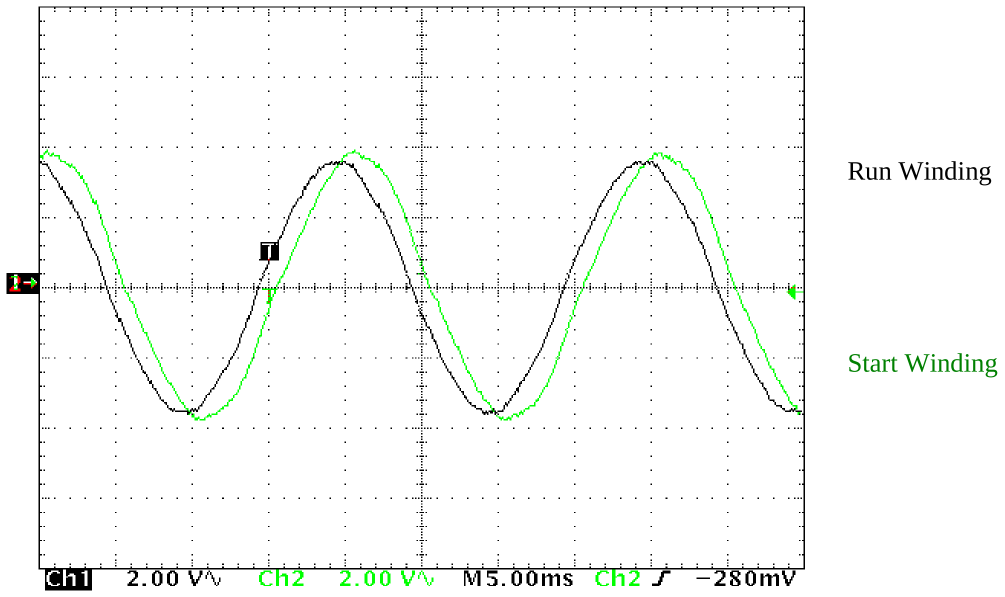
When running, the continuous rotational motion of the motor and magnetic field induces a voltage in the now redundant start winding. During normal running conditions there is a measurable phase difference between the start and run windings. This is illustrated in the following diagrams.

2.1.1 Run and Start Winding Before Rotation



In the above stalled condition the windings are in phase.

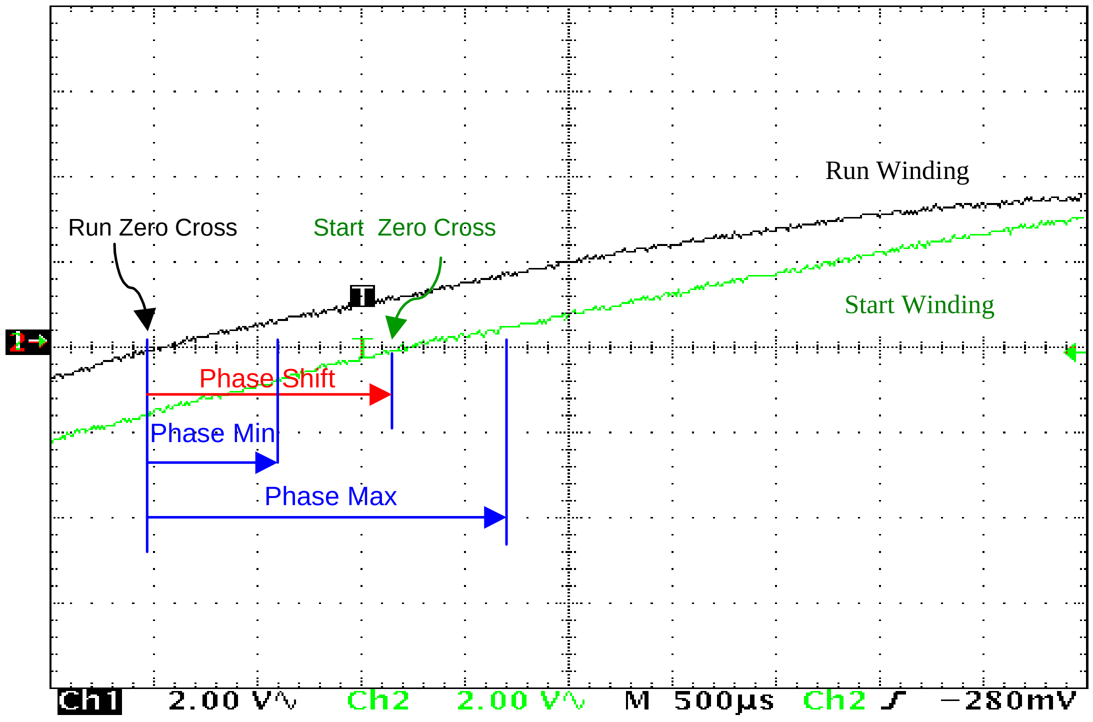
2.1.2 Phase Difference During Run Condition



Normal run conditions yields a phase difference between the run and start windings.

2.2 Phase Difference Measurement Process

The phase difference between the start and run windings is approximately 1mS. The presence of this difference is an indication of motor rotation. When the motor is not rotating, there is no difference in phase between the start and run windings. This change in behavior provides the measurement source for the Microcontroller. The following diagram illustrates the measurement process.

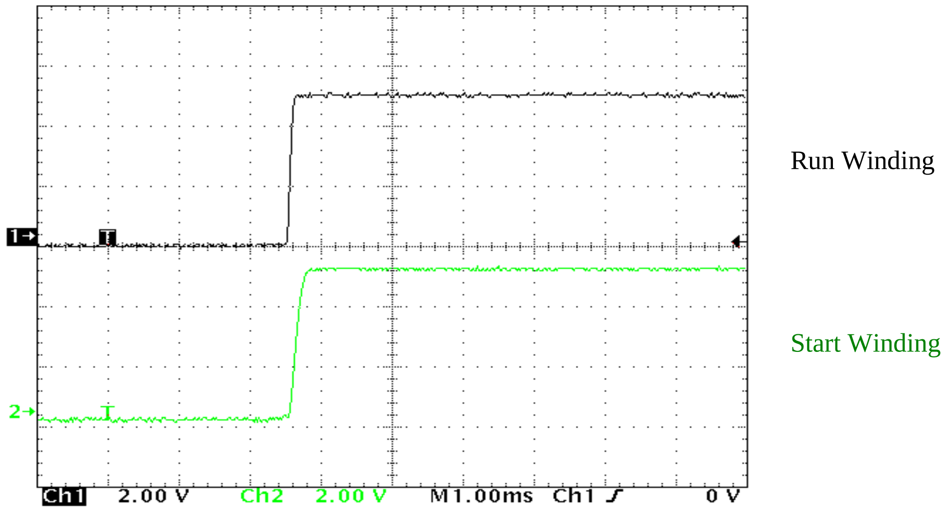


The ‘phase shift’ is the actual phase difference between the run and start windings. ‘phase min’ and ‘phase max’ define the acceptable tolerance band for the detection of the start zero cross point from the run zero cross reference point.

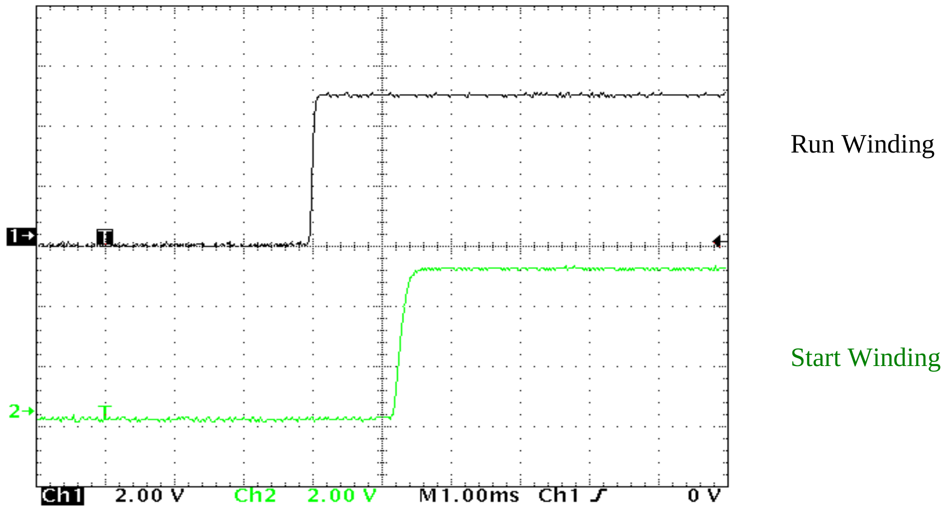
2.3 AC Line Signal Conditioning

The zero cross detect circuit conditions the above waveforms into usable digital signals which result as a series of pulses switched between 0V and Vdd at half the period of the AC line frequency, in this case 10mS. The digital signals derived from the zero crossing points of the run and start windings are input to the Microcontroller input capture pins. A sample of the digital waveforms applied to the input capture pins follows.

2.3.1 Input to Microcontroller Before Rotation



2.3.2 Input to Microcontroller During Run Condition



This is the digital representation of the phase difference between the run and start windings during normal running conditions.

2.4 Detection Algorithm

The algorithm will monitor the continuous presence of pulses on the input capture pins derived from the run and start windings. If the pulses are not detected in the appropriate sequence and time frame, the motor can be considered as being in a stalled condition and appropriate action can be taken, for example, by removing power from the motor and raising an audible alarm. Alternatively, one input capture pin can be used to monitor the run winding and the start winding can be monitored using an input port. This would require additional code to poll the port pin in a timely sense. The method described here takes advantage of both input captures.

2.5 Consecutive Detection

The detection operation is as follows. Every time a zero crossing point is detected on the run winding, it is expected that a zero cross point should be detected on the start winding approximately 1mS later. The timing between the run and start zero cross points is measured with an appropriate tolerance band included in the measurement.

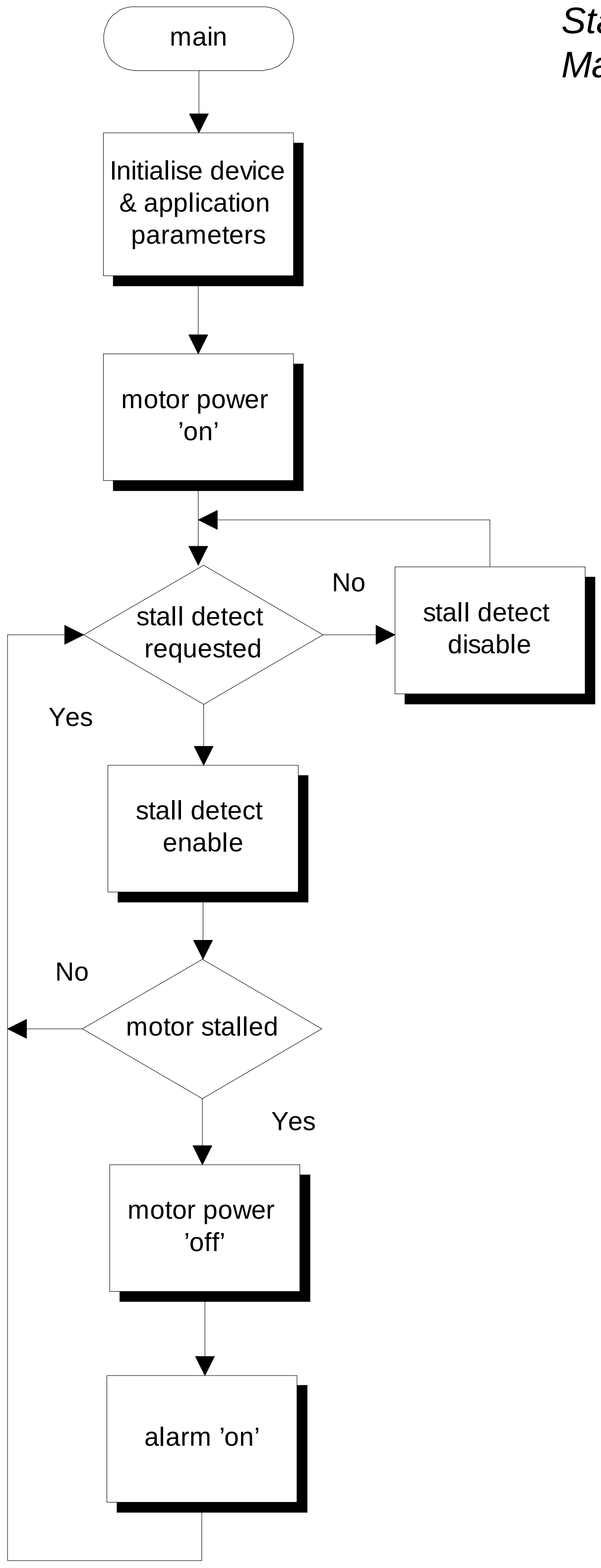
The algorithm is arranged to use the run zero cross points as a time reference. Each time a ‘run’ zero cross point is detected, the ‘run’ interrupt service routine is entered and the time of this event is latched. Approximately 1mS later the start winding zero cross point will be detected and the ‘start’ interrupt service routine will be entered. The time of this event will be latched also.

It is reasonable to expect that noise can influence the quality of the detected signal from either the start or run winding, and to compensate for this possibility, the algorithm will expect that zero cross detections should be consecutive. If for example a ‘run’ winding zero cross point is detected and the corresponding ‘start’ zero cross point is not detected within the expected time, this event will be identified as an error. A predefined number of non-consecutive zero cross errors will be tolerated before power-down and alarm action is invoked.

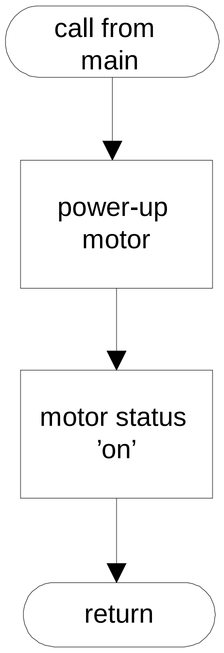
3 Flowcharts

The following flowcharts demonstrate an algorithm which implements stall/rotation detection of an induction motor refrigeration compressor. The algorithm is implemented from a main routine that controls the detection through two interrupt service routines, and also controls the power to the motor. It includes the facility to raise an audible alarm when the motor rotation is not in the expected state.

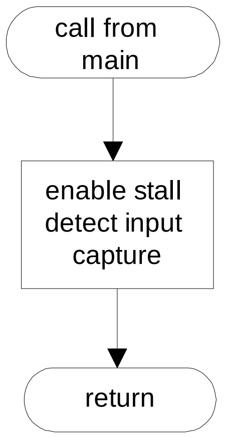
Stall Detect
Main Routine



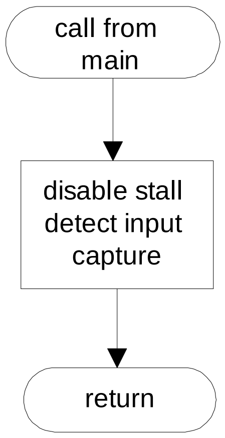
Motor ‘On’ Routine



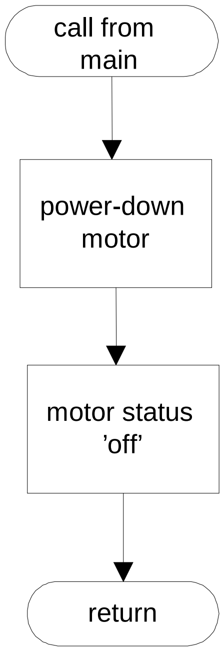
Enable Stall Detect Routine



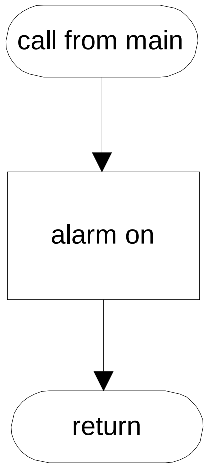
Disable Stall Detect Routine

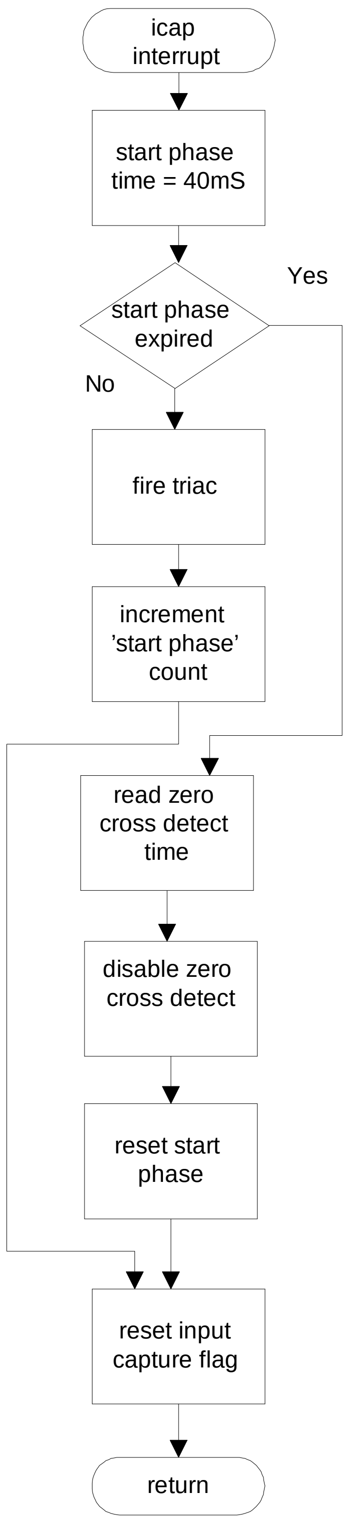


Motor 'Off' Routine



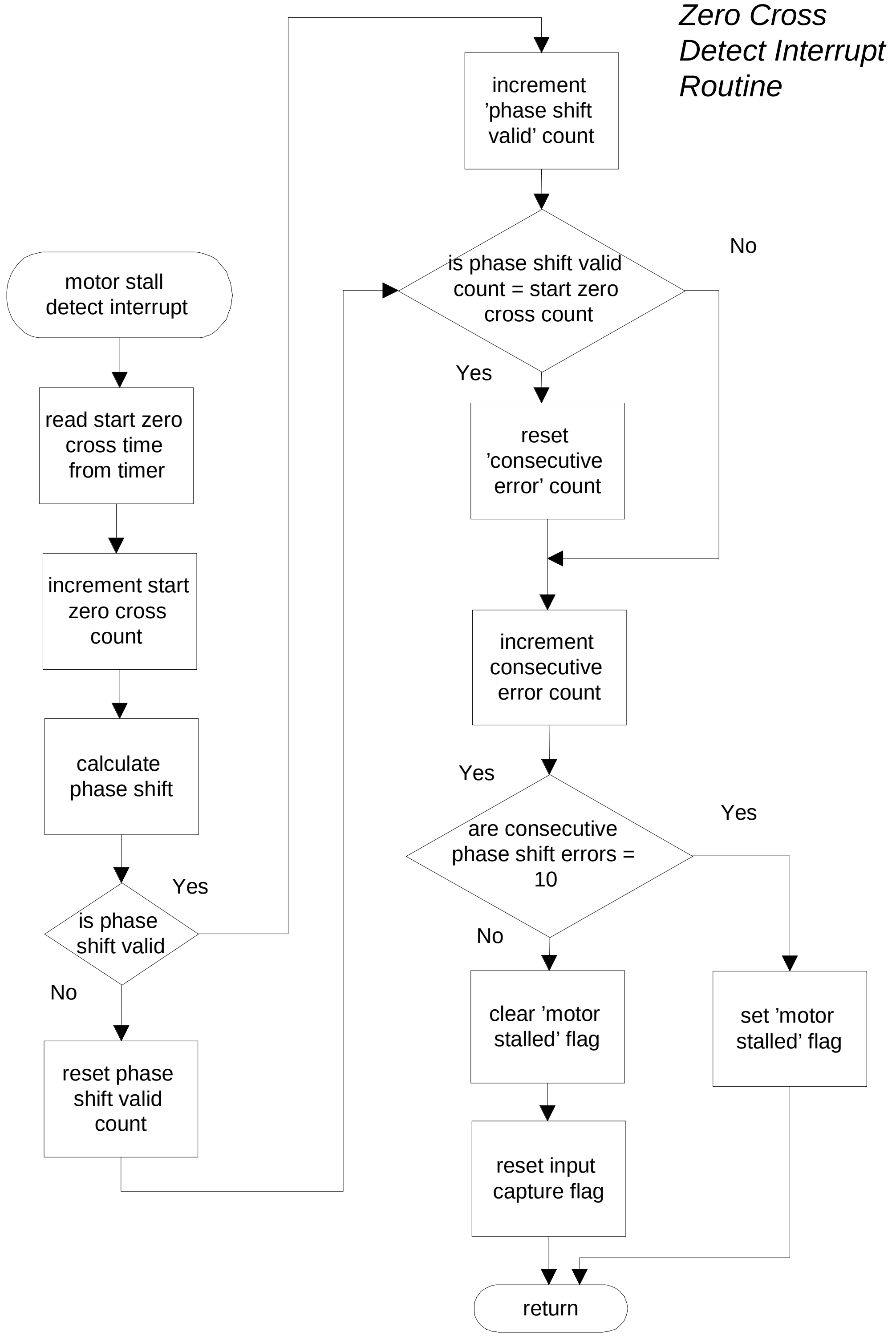
Alarm 'On' Routine





AC Line Zero Cross Detect Input Capture Interrupt Routine

Start Winding Zero Cross Detect Interrupt Routine



motor stall detect interrupt
read start zero cross time from timer
increment start zero cross count
calculate phase shift
is phase shift valid
Yes
No
reset phase shift valid count
increment 'phase shift valid' count
is phase shift valid count = start zero cross count
No
Yes
reset 'consecutive error' count
increment consecutive error count
Yes
are consecutive phase shift errors = 10
Yes
No
clear 'motor stalled' flag
set 'motor stalled' flag
reset input capture flag
return

4 Summary

There are many situations where it is convenient and sometimes necessary to have confirmation that the motor is in fact rotating when power is applied to the compressor. In the conventional arrangement the motor was protected from thermal damage by a bi-metallic contact. The Microcontroller can now manage this situation, decisions can be taken in the software based on the zero cross detection events of the run and start windings. In this way the motor can be protected from taking excessive power when in a stalled condition, therefore excessive winding temperature situations can be prevented from power-on. Additional thermal protection can also be included by connecting a sensor to the analogue to digital converter to continuously monitor motor temperature.

In applications that demand increased operational safety, knowing that the motor is rotating can be used as a comparative reference parameter for closed loop system integrity, safety measurements, or logic state confirmation checks. For example, in a pressurised system, if motor rotation is confirmed it can be expected that some time later the system should have achieved a specific pressure value. This can be measured using a pressure sensor and one of the analogue to digital converter inputs of the Microcontroller. Flow measurement can be achieved using a simple in-line switch connected to the device input/output ports. In these situations the Microcontroller can confirm motor rotation and compare with the feedback parameters measured within the software control loop.

Single-phase induction motors are widely used in ratings of 1hp and less, rarely greater than 10 hp. This power range of motors can meet the low through higher starting torque demands which are required for many household and industrial appliances, such as fans, which have a low starting torque and the higher starting torque demands of pumps, air conditioning units, and refrigeration compressors. As well as being a cost-effective solution, the adaptability and programmability of the Microcontroller can make a significant impact in the control, safety and efficiency of these and appliances.

5 Code

During the initial start-up phase, the probability of a stall condition is higher. This typically can be caused by mechanical failure where the motor is unable to start due to an obstruction, or an electrical failure when the motor is unable to start due to internal winding damage or component failure. However, it may be convenient in some systems to extend this feature to monitor the rotation of the motor at any time during the normal operational cycle of the application. The following code has been structured such that functions can be included in the application and called at any time from power-on in a convenient way. A main routine is used to demonstrate the implementation of the code as described in the preceding flowcharts.

```
#include "hc08kx8.h"        /* generic hc08kx8 header file*/
#include "stall.h"          /* application header file */
```

5.1 Main Routine

```
/*******************************************************************************
                                  Copyright (c) Motorola 2000

Function Name        :      main()

Engineer             :      William Mackay

Location             :      Motorola Microcontroller Division, East Kilbride

Date Created         :      March 2000

Current Revision     :      0.0

Note                 :      Main routine applies power to the motor, enables
                            or disables stall detection and powers the motor
                            down based on the condition of a flag which is
                            controlled in the stall detect ISR.

*******************************************************************************/

void main(void)
{
    init();
    motor_on();
    while(1)
    {
        if(STALL_DETECT_SELECT == ENABLED)   /* port pin high */
        {
            stall_detect_enable();           /* enable stall detect input capture */
            if(motor_stalled)                /* after start phase expired */
            {
                    motor_off();             /* remove power from motor */
                    alarm_on();              /* audible alarm */
            }
        }
        else
        {
            stall_detect_disable();
        }
    }
}
```

5.2 Initialisation Routine

```
/*******************************************************************************
                                  Copyright (c) Motorola 2000

Function Name        :      init()

Engineer             :      William Mackay

Location             :      Motorola Microcontroller Division, East Kilbride

Date Created         :      March 2000

Current Revision     :      0.0

Note                 :      Function configures oscillator, device modules
                            and initialises application parameters

*******************************************************************************/

void init(void)
{
   config();                    /* sets configuration register */
   init_osc();                  /* sets oscillator frequency */
   init_ports();                /* configure input/output ports */
   init_timer();                /* initialise timer */
   init_icap();                 /* configure input capture pin */
   init_application();          /* initialises application parameters */
}
```

5.3 Configuration Routine

```
/*******************************************************************************
                                  Copyright (c) Motorola 2000

Function Name        :      config()

Engineer             :      William Mackay

Location             :      Motorola Microcontroller Division, East Kilbride

Date Created         :      March 2000

Current Revision     :      0.0

Note                 :      Function configures device configuration register

*******************************************************************************/

void config()
{
   CONFIG1= 0x31;               /* disables lvi and cop */
}
```

5.4 Oscillator Initialisation Routine

```
/*******************************************************************************
                                 Copyright (c) Motorola 2000

Function Name        :      init_osc()

Engineer             :      William Mackay

Location             :      Motorola Microcontroller Division, East Kilbride

Date Created         :      March 2000

Current Revision     :      0.0

Note                 :      Function sets oscillator frequency

*******************************************************************************/

void init_osc(void)
{
   ICGMR_N0 = SET;                    /* set oscillator frequency */
   ICGMR_N1 = RESET;                  /* multipier set for 29x307.2khz = 8.9Mhz */
   ICGMR_N2 = SET;                    /* = 2.27Mhz bus freq */
   ICGMR_N3 = SET;
   ICGMR_N4 = SET;
   ICGMR_N5 = RESET;
   ICGMR_N6 = RESET;
}
```

5.5 Initialise Input Output Ports Routine

```
/******************************************************************************
                                  Copyright (c) Motorola 2000

Function Name        :      init_ports()

Engineer             :      William Mackay

Location             :      Motorola Microcontroller Division, East Kilbride

Date Created         :      March 2000

Current Revision     :      0.0

Note                 :      Configures input output ports

*******************************************************************************/

void init_ports(void)
{
    DDRA_BIT0 = OUTPUT;                 /* relay */
    DDRA_BIT1 = OUTPUT;                 /* buzzer */
    DDRA_BIT4 = INPUT;                  /* door */
    PTAPUE_BIT4 = SET;                  /* enable pull-up */

    DDRB_BIT0 = INPUT;                  /* UPDATE check adc init air temp adc */
    DDRB_BIT1 = INPUT;                  /* evaporator temp adc */
    DDRB_BIT2 = INPUT;                  /* temp select */

    DDRB_BIT3 = OUTPUT;                 /* yellow motor ’on’ led */
    DDRB_BIT6 = OUTPUT;                 /* triac drive */
    DDRB_BIT5 = OUTPUT;                 /* power ’on’ red led */
    DDRB_BIT4 = OUTPUT;                 /* alarm on-green led */
}
```

5.6 Timer Initialisation Routine

```
/*******************************************************************************
                                  Copyright (c) Motorola 2000

Function Name       :     init_timer()

Engineer            :     William Mackay

Location            :     Motorola Microcontroller Division, East Kilbride

Date Created        :     March 2000

Current Revision    :     0.0

Note                :     Function used to configure timer interface module.
                          Sets internal bus clock pre-scalar for timer counter

*******************************************************************************/

void init_timer(void)
{
   TSC = RESET;           /* internal bus clock divide by 1 */
}
```

5.7 Input Capture Initialisation Routine

```
/******************************************************************************
                                 Copyright (c) Motorola 2000

Function Name        :      init_icap()

Engineer             :      William Mackay

Location             :      Motorola Microcontroller Division, East Kilbride

Date Created         :      March 2000

Current Revision     :      0.0

Note                 :      This function configures timer channel zero and
                            Channel 1 as input capture for rising and falling edge
                            detection

******************************************************************************/

void init_icap(void)
{
   TSC_TSTOP   =  RESET;              /* start timer */
   TSC0_MS0A   =  RESET;              /* mode select = input capture */
   TSC0_MS0B   =  RESET;
   TSC0_ELS0A  =  SET;                /* capture on rising or falling edge */
   TSC0_ELS0B  =  SET;
   TSC0_CH0IE  =  RESET;              /* enable interrupts */

   TSC1_MS1A   =  RESET;              /* mode select = input capture */
   TSC1_ELS1A  =  SET;                /* capture on rising or falling edge */
   TSC1_ELS1B  =  SET;
   TSC1_CH1F   =  RESET;              /* clear flag*/
   TSC1_CH1IE  =  SET;                /* enable interrupts */
}
```

5.8 Initialise Application Routine

```
/******************************************************************************
                                  Copyright (c) Motorola 2000

Function Name        :      init_application()

Engineer             :      William Mackay

Location             :      Motorola Microcontroller Division, East Kilbride

Date Created         :      March 2000

Current Revision     :      0.0

Note                 :      Function initialises application parameters

******************************************************************************/

void init_application()
{
    POWER_STATUS = ON;                           /* red led */
    MOTOR_POWER = DISABLED;                      /* motor relay de-energised */
    MOTOR_STATUS = OFF;                          /* green led */
    TRIAC_DRIVE = DISABLED;                      /* triac off */
    BUZZER = OFF;
    ALARM_STATUS = OFF;                          /* yellow led */
    ZERO_CROSS_DETECT = ENABLED;                 /* start motor at next zero cross */
    stall_detect_disable();                      /* enable stall detect input capture */
    ENABLE_INTERRUPTS;                           /* enable interrupts */
}
```

5.9 Motor ‘on’ Routine

```
/******************************************************************************
                                  Copyright (c) Motorola 2000

Function Name        :      motor_on()

Engineer             :      William Mackay

Location             :      Motorola Microcontroller Division, East Kilbride

Date Created         :      March 2000

Current Revision     :      0.0

Note                 :      Function powers-on motor

******************************************************************************/

void motor_on(void)
{
    MOTOR_POWER = ENABLED;                 /* motor relay energised */
    MOTOR_STATUS = ON;
}
```

5.10 Stall Detect Enable Routine

```
/*******************************************************************************
                                  Copyright (c) Motorola 2000

Function Name        :      stall_detect_enable()

Engineer             :      William Mackay

Location             :      Motorola Microcontroller Division, East Kilbride

Date Created         :      March 2000

Current Revision     :      0.0

Note                 :      Enables stall detection

********************************************************************************/

void stall_detect_enable()
{
    if(start_phase == RESET             /* initial motor start phase complete */
    {
        MOTOR_STALL_DETECT = ENABLED;
    }
}
```

5.11 Motor ‘off’ Routine

```
/*******************************************************************************
                                  Copyright (c) Motorola 2000

Function Name        :      motor_off()

Engineer             :      William Mackay

Location             :      Motorola Microcontroller Division, East Kilbride

Date Created         :      March 2000

Current Revision     :      0.0

Note                 :      Function powers-down motor

********************************************************************************/

void motor_off(void)
{
    MOTOR_POWER = DISABLED;             /* motor relay de-energised */
    ZERO_CROSS_DETECT = DISABLED;       /* disable icap interrupt */
    MOTOR_STATUS = OFF;                 /* motor led */
}
```

5.12 Alarm ‘on’ Routine

```
/*******************************************************************************
                                  Copyright (c) Motorola 2000

Function Name        :      alarm_on()

Engineer             :      William Mackay

Location             :      Motorola Microcontroller Division, East Kilbride

Date Created         :      March 2000

Current Revision     :      0.0

Note                 :      Function invokes alarm status and audible alarm

*******************************************************************************/

void alarm_on(void)
{
    ALARM_STATUS = ON;
    BUZZER = ON;
}
```

5.13 Stall Detect Disable Routine

```
/*******************************************************************************
                                  Copyright (c) Motorola 2000

Function Name        :      stall_detect_disable()

Engineer             :      William Mackay

Location             :      Motorola Microcontroller Division, East Kilbride

Date Created         :      March 2000

Current Revision     :      0.0

Note                 :      Disables stall detection


*******************************************************************************/

void stall_detect_disable()
{
    if(start_phase == RESET)            /* initial motor start phase complete */
    {
         MOTOR_STALL_DETECT = DISABLED;
    }
}
```

5.14 Delay Routine

```
/*****************************************************************************
                                 Copyright (c) Motorola 2000

Function Name        :      delay()

Engineer             :      William Mackay

Location             :      Motorola Microcontroller Division, East Kilbride

Date Created         :      March 2000

Current Revision     :      0.0

Note                 :      This delay for triac pulse period

*****************************************************************************/

void delay(void)
{
    unsigned char i,j;
    for(i=0; i<2; i++)
    {
        for(j=0; j<1; j++);
    }
}
```

5.15 Input Capture Routine

```
/*****************************************************************************
                                 Copyright (c) Motorola 2000

Function Name        :      input_capture()

Engineer             :      William Mackay

Location             :      Motorola Microcontroller Division, East Kilbride

Date Created         :      March 2000

Current Revision     :      0.0

Note                 :      This ISR pulses the triac when line voltage zero-cross
                            Is detected, for a pre-defined motor start period

******************************************************************************/

#pragma TRAP_PROC SAVE_REGS
void Input_Capture(void)
{
    if(start_phase != START_TIME                         /* start phase valid */
    {
        TRIAC_DRIVE = OFF;                               /* apply pulse to triac */
        delay();
        TRIAC_DRIVE = ON;
        ++start_phase;                                   /* start phase is a count of the */
    }                                                    /* line voltage zero cross points */
    else
    {                                                    /* start time has expired */
        timer_ch0.count.timer_high = TIMER_CH0_HIGH;     /* read high byte of counter */
        timer_ch0.count.timer_low = TIMER_CH0_LOW;       /* read low byte of counter */
        ZERO_CROSS_DETECT = DISABLED;                    /* disable timer ch 0 icap interrupt */
        MOTOR_STALL_DETECT = ENABLED;                    /* enable timer ch1 icap interrupt */
        start_phase = RESET;                             /* reset start phase */
    }
    read_register = TSC0;                                /* reads TIM status and control regr */
    ICAP0_FLAG = RESET;                                  /* resets CH0F flag */
}
```

5.16 Stall Detection Routine

```
/*******************************************************************************
                                  Copyright (c) Motorola 2000

Function Name       :      stall_detect()

Engineer            :      William Mackay

Location            :      Motorola Microcontroller Division, East Kilbride

Date Created        :      March 2000

Current Revision    :      0.0

Note                :      This ISR detects the induced voltage in the motor
                           start winding after the initial start phase has expired.

*******************************************************************************/

#pragma TRAP_PROC SAVE_REGS
void Stall_Detect(void)
{
    timer_ch1.count.timer_high = TIMER_CH1_HIGH;    /* read high byte of counter */
    timer_ch1.count.timer_low = TIMER_CH1_LOW;      /* read low byte of counter */
    ++start_zero_cross;                             /* cumulative count of start zero cross points */
    if(timer_ch1.timer_count > timer_ch0.timer_count)
    {
        phase_shift = (timer_ch1.timer_count - timer_ch0.timer_count);
    }
    else
    {
        phase_shift = (TIMER_COUNT_MAX - timer_ch0.timer_count + timer_ch1.timer_count)
    }                                               /*accomodates counter rollover */
    if((timer_ch1.timer_count >= (timer_ch0.timer_count + phase_shift - PHASE_MIN))&&
    (timer_ch1.timer_count <= (timer_ch0.timer_count + phase_shift + PHASE_MAX)))
    {                                               /* checks phase shift tolerance */
        ++phase_shift_valid;                        /* cumulative count of valid phase shifts */
    }                                               /* each zero cross should have a valid phase shift */
    else
    {
        phase_shift_valid = RESET;
    }
    if(phase_shift_valid != start_zero_cross)       /* both counts are not the same */
    {
        ++consecutive_error;                        /* cumulative count of phase shift errors */
    }
    else
    {
        consecutive_error = RESET;
    }
    if(consecutive_error >= PHASE_ERROR_COUNT_MAX)
    {
        motor_stalled = SET;                        /* indicates motor has stalled */
    }
    else
    {
        motor_stalled = RESET;                      /* motor is rotating */
    }
    read_register = TSC1;                           /* reads TIM status and control regr */
    ICAP1_FLAG = RESET;                             /* resets CH1F flag */
}
```

5.17 HC08KX8 Generic Header File

```
/*******************************************************************************
                                  Copyright (c) Motorola 1999

File Name           :      HC08KX8.h

Org Author          :      William Mackay

Location            :      Motorola Microcontroller Division, East Kilbride

Date Created        :      December 1999

Current Revision    :      0.0

Notes               :      This file maps the 68HC908KX8 register set as defined
                           in the General Release Specification.

*******************************************************************************/

#ifndef _HC08KX8_H
#define _HC08KX8_H


/*****************************************************************************/
/* Register Mapping Structures and Macros                                    */
/*****************************************************************************/

#define REGISTER(a) (*((volatile unsigned char *)(a)))
#define BIT(a,b) (((vbitfield *)(a))->bit##b)

/* assumes right to left bit order */

typedef volatile struct{
    volatile unsigned int bit0 : 1;
    volatile unsigned int bit1 : 1;
    volatile unsigned int bit2 : 1;
    volatile unsigned int bit3 : 1;
    volatile unsigned int bit4 : 1;
    volatile unsigned int bit5 : 1;
    volatile unsigned int bit6 : 1;
    volatile unsigned int bit7 : 1;
} vbitfield;

typedef union
{
    struct{
             unsigned char timer_high;
             unsigned char timer_low;
         }   count;
    unsigned short timer_count;
}TIMER;

TIMER timer_ch0;
TIMER timer_ch1;
```

```
/*****************************************************************************/
/* Input Output Ports                                                        */
/*****************************************************************************/

/* Port A Data register */
#define      PTA            REGISTER(0x00)
#define      PTA_BIT0       BIT(0x00,0)
#define      PTA_BIT1       BIT(0x00,1)
#define      PTA_BIT2       BIT(0x00,2)
#define      PTA_BIT3       BIT(0x00,3)
#define      PTA_BIT4       BIT(0x00,4)

/* Port B Data register */
#define      PTB            REGISTER(0x01)
#define      PTB_BIT0       BIT(0x01,0)
#define      PTB_BIT1       BIT(0x01,1)
#define      PTB_BIT2       BIT(0x01,2)
#define      PTB_BIT3       BIT(0x01,3)
#define      PTB_BIT4       BIT(0x01,4)
#define      PTB_BIT5       BIT(0x01,5)
#define      PTB_BIT6       BIT(0x01,6)
#define      PTB_BIT7       BIT(0x01,7)

/* Port A Data Direction Register */
#define      DDRA           REGISTER(0x04)
#define      DDRA_BIT0      BIT(0x04,0)
#define      DDRA_BIT1      BIT(0x04,1)
#define      DDRA_BIT2      BIT(0x04,2)
#define      DDRA_BIT3      BIT(0x04,3)
#define      DDRA_BIT4      BIT(0x04,4)

/* Port A Input Pull Up Enable Register */
#define      PTAPUE         REGISTER(0x0D)
#define      PTAPUE_BIT0    BIT(0x0D,0)
#define      PTAPUE_BIT1    BIT(0x0D,1)
#define      PTAPUE_BIT2    BIT(0x0D,2)
#define      PTAPUE_BIT3    BIT(0x0D,3)
#define      PTAPUE_BIT4    BIT(0x0D,4)

/* Port B Data Direction Register */
#define      DDRB           REGISTER(0x05)
#define      DDRB_BIT0      BIT(0x05,0)
#define      DDRB_BIT1      BIT(0x05,1)
#define      DDRB_BIT2      BIT(0x05,2)
#define      DDRB_BIT3      BIT(0x05,3)
#define      DDRB_BIT4      BIT(0x05,4)
#define      DDRB_BIT5      BIT(0x05,5)
#define      DDRB_BIT6      BIT(0x05,6)
#define      DDRB_BIT7      BIT(0x05,7)
```

```
/****************************************************************************/
/* Time Base Register                                                       */
/****************************************************************************/

#define      TBCR           REGISTER(0x1C)
#define      TBCR_TBON      BIT(0x1C,1)
#define      TBCR_TBIE      BIT(0x1C,2)
#define      TBCR_TACK      BIT(0x1C,3)
#define      TBCR_TBR0      BIT(0x1C,4)
#define      TBCR_TBR1      BIT(0x1C,5)
#define      TBCR_TBR2      BIT(0x1C,6)
#define      TBCR_TBIF      BIT(0x1C,7)


/****************************************************************************/
/* Configuration Write-Once Registers                                       */
/****************************************************************************/

#define      CONFIG2        REGISTER(0x1e)
#define      CONFIG1        REGISTER(0x1F)


/****************************************************************************/
/* Timer Registers                                                          */
/****************************************************************************/

/* Timer Status and Control Register */
#define      TSC            REGISTER(0x20)
#define      TSC_PS0        BIT(0x20,0)
#define      TSC_PS1        BIT(0x20,1)
#define      TSC_PS2        BIT(0x20,2)
#define      TSC_TRST       BIT(0x20,4)
#define      TSC_TSTOP      BIT(0x20,5)
#define      TSC_TOIE       BIT(0x20,6)
#define      TSC_TOF        BIT(0x20,7)

/* Timer Counter Register */
#define      TCNTH          REGISTER(0x21)
#define      TCNTL          REGISTER(0x22)

/* Timer Modulo Register */
#define      TMODH          REGISTER(0x23)
#define      TMODL          REGISTER(0x24)

/* Timer Status and Control Register Channel 0 */
#define      TSC0           REGISTER(0x25)
#define      TSC0_CH0MAX    BIT(0x25,0)
#define      TSC0_TOV0      BIT(0x25,1)
#define      TSC0_ELS0A     BIT(0x25,2)
#define      TSC0_ELS0B     BIT(0x25,3)
#define      TSC0_MS0A      BIT(0x25,4)
#define      TSC0_MS0B      BIT(0x25,5)
#define      TSC0_CH0IE     BIT(0x25,6)
#define      TSC0_CH0F      BIT(0x25,7)
```

```
/* Timer Channel 0 Register */
#define      TCH0H          REGISTER(0x26)
#define      TCH0L          REGISTER(0x27)

/* Timer Status and Control Register Channel 1 */
#define      TSC1           REGISTER(0x28)
#define      TSC1_CH1MAX    BIT(0x28,0)
#define      TSC1_TOV1      BIT(0x28,1)
#define      TSC1_ELS1A     BIT(0x28,2)
#define      TSC1_ELS1B     BIT(0x28,3)
#define      TSC1_MS1A      BIT(0x28,4)
#define      TSC1_CH1IE     BIT(0x28,6)
#define      TSC1_CH1F      BIT(0x28,7)

/* Timer Channel 1 Register */
#define      TCH1H          REGISTER(0x29)
#define      TCH1L          REGISTER(0x2a)


/****************************************************************************/
/* ICG Registers                                                            */
/****************************************************************************/

/* ICG Control Register */
#define      ICGCR          REGISTER(0x36)
#define      ICGCR_ECGS     BIT(0x36,0)
#define      ICGCR_ECGON    BIT(0x36,1)
#define      ICGCR_ICGS     BIT(0x36,2)
#define      ICGCR_ICGON    BIT(0x36,3)
#define      ICGCR_CS       BIT(0x36,4)
#define      ICGCR_CMON     BIT(0x36,5)
#define      ICGCR_CMF      BIT(0x36,6)
#define      ICGCR_CMIE     BIT(0x36,7)

/* ICG Multiply Register */
#define      ICGMR          REGISTER(0x37)
#define      ICGMR_N0       BIT(0x37,0)
#define      ICGMR_N1       BIT(0x37,1)
#define      ICGMR_N2       BIT(0x37,2)
#define      ICGMR_N3       BIT(0x37,3)
#define      ICGMR_N4       BIT(0x37,4)
#define      ICGMR_N5       BIT(0x37,5)
#define      ICGMR_N6       BIT(0x37,6)

/* ICG Trim Register */
#define      ICGTR          REGISTER(0x38)
#define      ICGTR_TRIM0    BIT(0x38,0)
#define      ICGTR_TRIM1    BIT(0x38,1)
#define      ICGTR_TRIM2    BIT(0x38,2)
#define      ICGTR_TRIM3    BIT(0x38,3)
#define      ICGTR_TRIM4    BIT(0x38,4)
#define      ICGTR_TRIM5    BIT(0x38,5)
#define      ICGTR_TRIM6    BIT(0x38,6)
#define      ICGTR_TRIM7    BIT(0x38,7)


/****************************************************************************/
/* Analogue To Digital Converter Registers                                  */
/****************************************************************************/

/* A/D Status and Control Register */
```

```
#define      ADSCR          REGISTER(0x3c)
#define      ADSCR_ADCH0    BIT(0x3c,0)
#define      ADSCR_ADCH1    BIT(0x3c,1)
#define      ADSCR_ADCH2    BIT(0x3c,2)
#define      ADSCR_ADCH3    BIT(0x3c,3)
#define      ADSCR_ADCH4    BIT(0x3c,4)
#define      ADSCR_ADCO     BIT(0x3c,5)
#define      ADSCR_AIEN     BIT(0x3c,6)
#define      ADSCR_COCO     BIT(0x3c,7)

/* A/D-Data Register */
#define      ADR            REGISTER(0x3d)

/* A/D Input Clock Register */
#define      ADCLK          REGISTER(0x3e)
#define      ADCLK_ADICLK   BIT(0x3e,4)
#define      ADCLK_ADIV0    BIT(0x3e,5)
#define      ADCLK_ADIV1    BIT(0x3e,6)
#define      ADCLK_ADIV2    BIT(0x3e,7)


/*****************************************************************************/
/* Low Voltage Inhibit Register                                             */
/*****************************************************************************/

/* LVI Status Register */
#define      LVISR          REGISTER(0xFE0C)
#define      LVISR_LVIOUT   BIT(0xFE0C,7)

#endif
```

5.18 Application Header File

```
/*******************************************************************************
                                  Copyright (c) Motorola 2000

File Name           :      StallDetect.h

Engineer            :      William Mackay

Location            :      Motorola Microcontroller Division, East Kilbride

Date Created        :      March 2000

Current Revision    :      0.0

Notes               :      This file contains application definitions

********************************************************************************/

#ifndef    _STALL_H
#define    _STALL_H


/*****************************************************************************/
/* Constant Definitions                                                      */
/*****************************************************************************/

#define    ON                0
#define    OFF               1
#define    SET               1
#define    RESET             0
#define    ENABLED           1
#define    DISABLED          0
#define    RESET             0
#define    OUTPUT            1
#define    INPUT             0

#define    START_TIME        0x28        /* motor start-up period (40mS) */
#define    STALL_PERIOD      0xFF        /* 255x10mS = 2.55Sec 0x07 motor stall time period (3 cycles) */
#define    TIMER_COUNT_MAX   0xFFFF      /* maximum value of timer counter */
#define    PHASE_MIN         0x0D50      /* 3408 */
#define    PHASE_MAX         0x0470      /* 1136 */
#define    PHASE_ERROR_COUNT_MAX  0x06


/*****************************************************************************/
/* Input/Output Port Application Definitions                                 */
/*****************************************************************************/

#define    MOTOR_POWER            PTA_BIT0
#define    BUZZER                 PTA_BIT1
#define    STALL_DETECT_SELECT    PTA_BIT4
#define    TRIAC_DRIVE            PTB_BIT6
#define    POWER_STATUS           PTB_BIT5
#define    MOTOR_STATUS           PTB_BIT3
#define    ALARM_STATUS           PTB_BIT4
```

```
/****************************************************************************/
/* Timer                                                                    */
/****************************************************************************/

#define      ZERO_CROSS_DETECT          TSC0_CH0IE
#define      ICAP0_FLAG                 TSC0_CH0F
#define      MOTOR_STALL_DETECT         TSC1_CH1IE
#define      ICAP1_FLAG                 TSC1_CH1F
#define      TIMER_CH0_HIGH             TCH0H
#define      TIMER_CH0_LOW              TCH0L
#define      TIMER_CH1_HIGH             TCH1H
#define      TIMER_CH1_LOW              TCH1L

/****************************************************************************/
/* Function Prototypes                                                      */
/****************************************************************************/

void main(void);
void config(void);
void init(void);
void init_ports(void);
void init_osc(void);
void init_timer(void);
void init_icap(void);
void init_application(void);
void delay(void);
void stall_detect_enable(void);
void stall_detect_disable();
void motor_on(void);
void motor_off(void);
void power_down(void);
void alarm_on(void);
void Input_Capture(void);
void Stall_Detect(void);



/****************************************************************************/
/* Global Variables                                                         */
/****************************************************************************/

/* Zero Page RAM variables */
#pragma      DATA_SEG _DATA_ZEROPAGE
unsigned     char    start_phase;            /* indicates status of start time interval */
unsigned     char    motor_stalled;          /* indicates motor start status */
unsigned     char    stall_time;             /* count for permitted stall time */
unsigned     char    read_register;          /* dummy read locatin for flag clearing */
unsigned     char    start_zero_cross;       /* count */
unsigned     int     phase_shift;            /* time storage */
unsigned     char    phase_shift_valid;      /* count */
unsigned     char    consecutive_error;      /* count */
/****************************************************************************/
/* Interrupt Definitions                                                    */
/****************************************************************************/

#define      ENABLE_INTERRUPTS          asm cli;
#define      DISABLE_INTERRUPTS         asm sei;

#endif
```

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