STM32 MC SDK5.0 培训

2018/06

MCU Application

Motor Control LAB

life.augmented

内容

- 上午
  1.MC SDK5.0算法的理论基础 (1小时)
  2.MC SDK5.0详解 (1小时)
  3.实验1： MC SDK5.0 电动机参数识别 (45分钟)
- 下午
  4.MC SDK5.0 工具链及图形用户界面 (1小时)
  5.MC SDK5.0 评估硬件 (15分钟)
  6.实验2： 基于MC SDK5.0 API， 速度控制与电机启动停止 (20分钟)
  7.实验3： 基于MC SDK5.0 PI 组件接口函数做在线参数修改 (20分钟)
  8.实验4： 基于MC SDK5.0 状态的切换 (20分钟)
  9.实验5： 开放性试验 (20分钟)
  10.实验总结及问答 (45分钟)

life.augmented

1.MC SDK5.0 算法的理论基础

life.augmented

MC SDK5.0算法概述

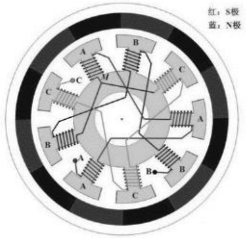
- 目标电机：三相永磁同步电动机（直流无刷电动机）
- 控制方法：矢量控制
- 三相PWM输出方法： SVPWM
- 相电流检测方法：
  - 单电阻电流检测和重构方式
  - 三电阻电流检测和重构方式
  - 隔离型电流传感器检测电流（DCCT或者ACCT）
- 转子位置检测方法
  - 霍尔效应位置传感器
  - 光电增量编码器
  - 无位置传感器的转子速度和位置估计算法
    - 基于估计感应电压的转子位置和速度估计算法
    - 基于高频载波注入的转子位置和估计算法

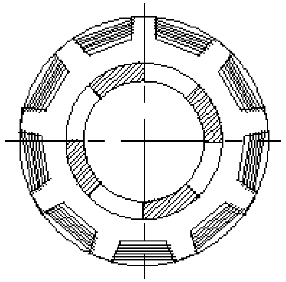
life.augmented

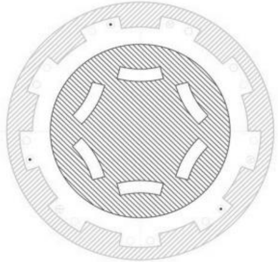
三相永磁同步电动机(直流无刷电动机)

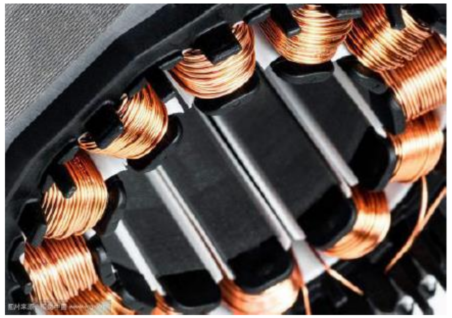
永磁同步电动机
(直流无刷电动机)

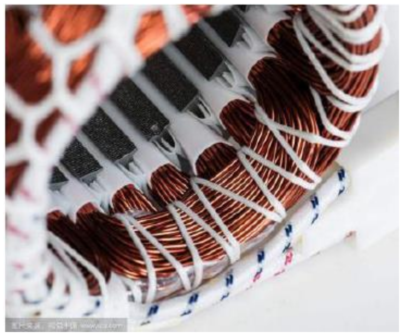
- 转子
  - 内转子/外转子
  - 表面贴装磁石或内嵌式磁石
- 绕组(定子) —— 集中绕组/分布绕组











life.augmented

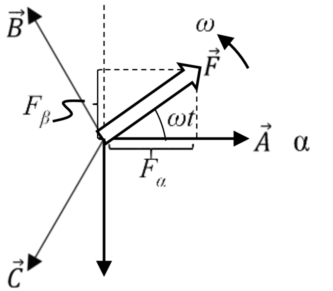
MCSDK5.0应用的永磁同步电动机的数学模型

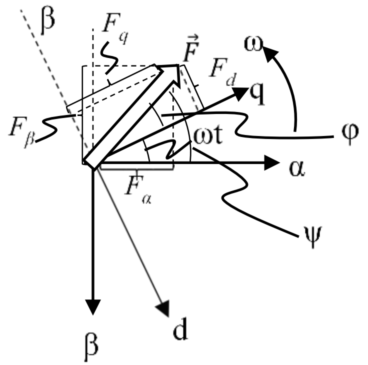
名称	方程式
电压方程	$\begin{bmatrix} U_d \\ U_q \end{bmatrix} = \begin{bmatrix} r + \frac{d}{dt} L_d & -L_q \omega_e \\ L_d \omega_e & r + \frac{d}{dt} L_q \end{bmatrix} \begin{bmatrix} I_d \\ I_q \end{bmatrix} + \begin{bmatrix} 0 \\ k_E \omega_e \end{bmatrix}$
转矩方程	$\tau_e = \frac{3}{2} p [k_E + (L_d - L_q) I_d] I_q$
弱磁控制条件	$(L_q I_q)^2 + (k_E + L_d I_d)^2 \le \frac{{U_{1-limit}}^2}{{\omega_e}^2}$
动力学方程	$\tau_e - \tau_L = J \frac{d\omega_r}{dt} + B\omega_r$

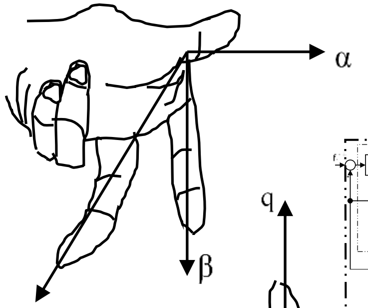
life.augmented

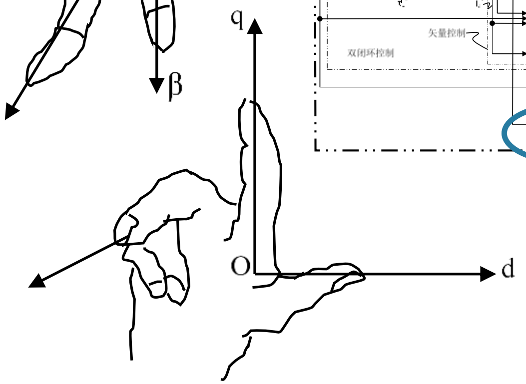
矢量控制 — 矢量变换

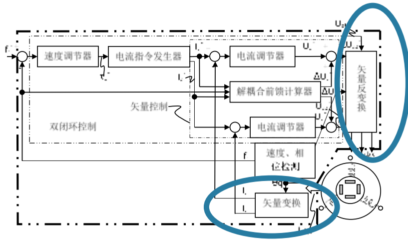
变换内容		变换前后幅值不变	变换前后瞬时功率不变
从三相到两相的变换	电压	$\begin{bmatrix}u_\alpha\\u_\beta\end{bmatrix}=\begin{bmatrix}1 & 0\\ -\frac{1}{\sqrt{3}} & -\frac{2}{\sqrt{3}}\end{bmatrix}\begin{bmatrix}u_A\\u_B\end{bmatrix}$	$\begin{bmatrix}u_\alpha\\u_\beta\end{bmatrix}=\begin{bmatrix}\sqrt{\frac{3}{2}} & 0\\ -\frac{1}{\sqrt{2}} & -\frac{2}{\sqrt{2}}\end{bmatrix}\begin{bmatrix}u_A\\u_B\end{bmatrix}$
	电流	$\begin{bmatrix}i_\alpha\\i_\beta\end{bmatrix}=\begin{bmatrix}1 & 0\\ -\frac{1}{\sqrt{3}} & -\frac{2}{\sqrt{3}}\end{bmatrix}\begin{bmatrix}i_A\\i_B\end{bmatrix}$	$\begin{bmatrix}i_\alpha\\i_\beta\end{bmatrix}=\begin{bmatrix}\sqrt{\frac{3}{2}} & 0\\ -\frac{1}{\sqrt{2}} & -\frac{2}{\sqrt{2}}\end{bmatrix}\begin{bmatrix}i_A\\i_B\end{bmatrix}$
从两相到三相的变换	电压	$\begin{bmatrix}u_A\\u_B\\u_C\end{bmatrix}=\begin{bmatrix}1 & 0\\ -\frac{1}{2} & -\frac{\sqrt{3}}{2}\\ -\frac{1}{2} & \frac{\sqrt{3}}{2}\end{bmatrix}\begin{bmatrix}u_\alpha\\u_\beta\end{bmatrix}$	$\begin{bmatrix}u_A\\u_B\\u_C\end{bmatrix}=\sqrt{\frac{2}{3}}\begin{bmatrix}1 & 0\\ -\frac{1}{2} & -\frac{\sqrt{3}}{2}\\ -\frac{1}{2} & \frac{\sqrt{3}}{2}\end{bmatrix}\begin{bmatrix}u_\alpha\\u_\beta\end{bmatrix}$
	电流	$\begin{bmatrix}i_A\\i_B\\i_C\end{bmatrix}=\begin{bmatrix}1 & 0\\ -\frac{1}{2} & -\frac{\sqrt{3}}{2}\\ -\frac{1}{2} & \frac{\sqrt{3}}{2}\end{bmatrix}\begin{bmatrix}i_\alpha\\i_\beta\end{bmatrix}$	$\begin{bmatrix}i_A\\i_B\\i_C\end{bmatrix}=\sqrt{\frac{2}{3}}\begin{bmatrix}1 & 0\\ -\frac{1}{2} & -\frac{\sqrt{3}}{2}\\ -\frac{1}{2} & \frac{\sqrt{3}}{2}\end{bmatrix}\begin{bmatrix}i_\alpha\\i_\beta\end{bmatrix}$
瞬时功率		$p_3=\frac{3}{2}p_2$	$p_3=p_2$
电磁力矩		$\tau_e=\frac{3}{2}p[k_E+(L_d-L_q)I_d]I_q$	$\tau_e=p[k_E+(L_d-L_q)I_d]I_q$









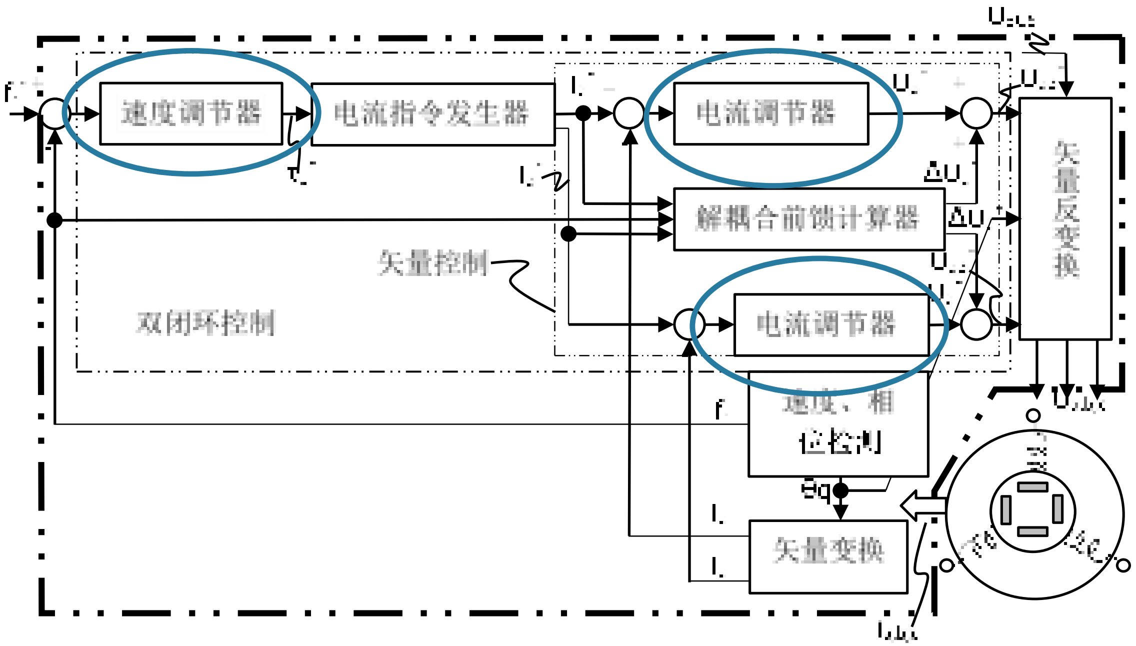


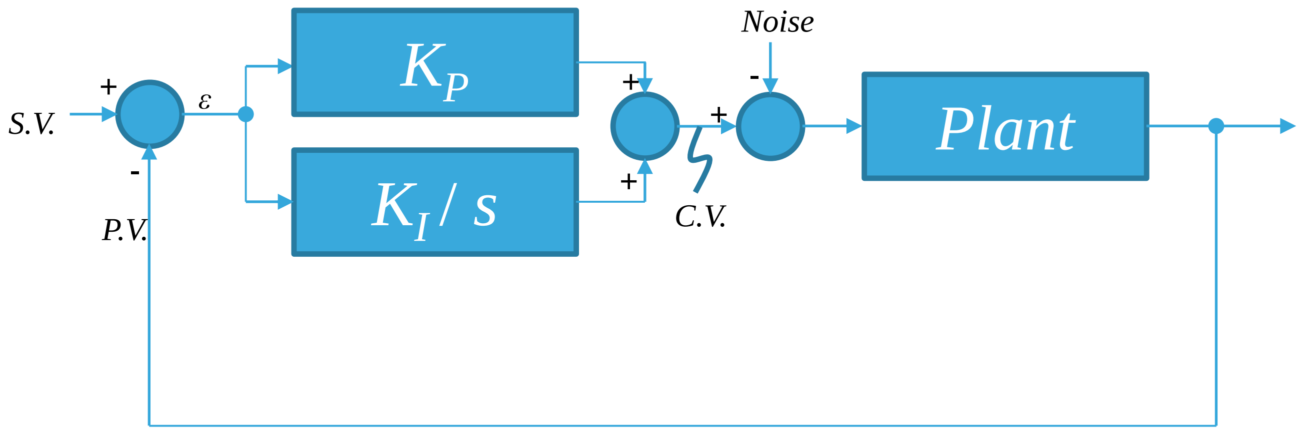
项目	电压	电流
αβ - dq	$\begin{bmatrix}U_d\\U_q\end{bmatrix}=\begin{bmatrix}\cos(\omega t) & \sin(\omega t)\\ -\sin(\omega t) & \cos(\omega t)\end{bmatrix}\begin{bmatrix}u_\beta\\u_\alpha\end{bmatrix}$	$\begin{bmatrix}I_d\\I_q\end{bmatrix}=\begin{bmatrix}\cos(\omega t) & \sin(\omega t)\\ -\sin(\omega t) & \cos(\omega t)\end{bmatrix}\begin{bmatrix}i_\beta\\i_\alpha\end{bmatrix}$
dq - αβ	$\begin{bmatrix}u_\alpha\\u_\beta\end{bmatrix}=\begin{bmatrix}\cos(\omega t) & \sin(\omega t)\\ -\sin(\omega t) & \cos(\omega t)\end{bmatrix}\begin{bmatrix}U_q\\U_d\end{bmatrix}$	$\begin{bmatrix}i_\alpha\\i_\beta\end{bmatrix}=\begin{bmatrix}\cos(\omega t) & \sin(\omega t)\\ -\sin(\omega t) & \cos(\omega t)\end{bmatrix}\begin{bmatrix}I_q\\I_d\end{bmatrix}$

- 变换前后功率和幅值都不改变。
- 变换矩阵可以使用同一个矩阵，但是输入量需要逆序输入，输出量需要顺序输出

life.augmented

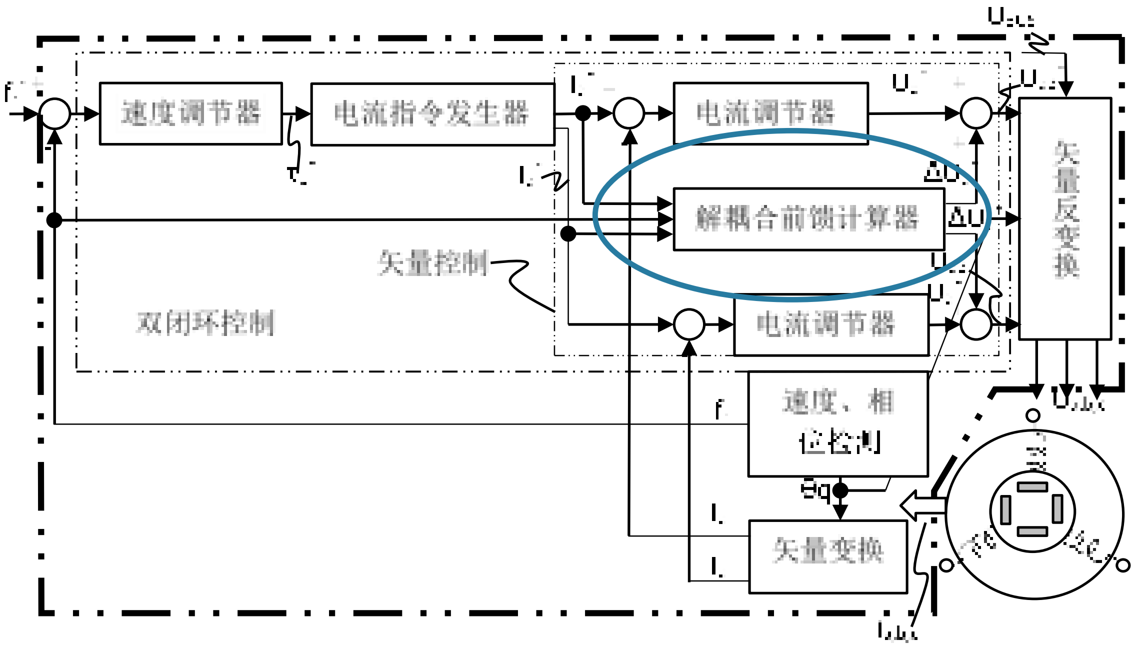
矢量控制 — 双闭环控制器





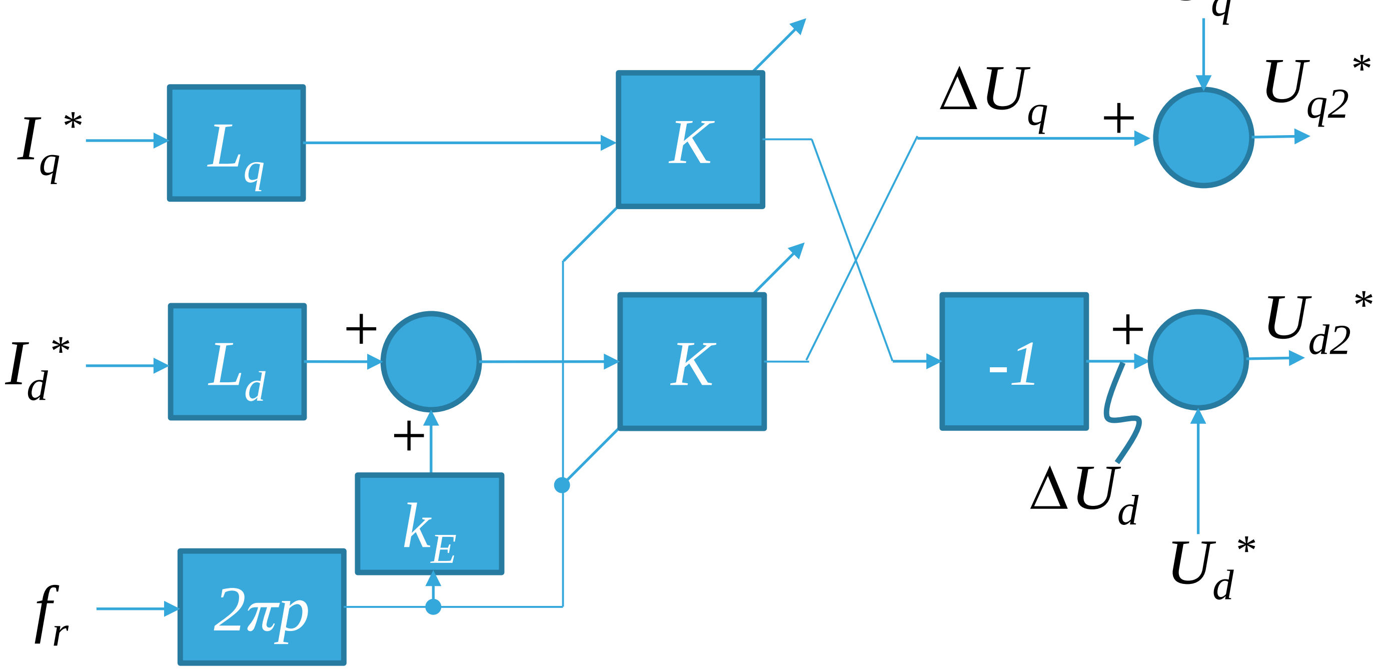
控制器	设定值S.V.	实际值 P.V.	控制值C.V.	对象传递函数
速度控制器	$f_{r\text{-}ref}(f_r^*)$	$f_{r\text{-}fb}(f_r)$	$\tau_{ref}(\tau^*)$ or $I_{q\text{-}ref}(I_q^*)$	$\frac{1}{Js+B}$
电流控制器（忽略dq之间的耦合）	$I_{d/q\text{-}ref}(I_{d/q}^*)$	$I_{d/q\text{-}fb}(I_{d/q})$	$U_{d/q\text{-}ref}(U_{d/q}^*)$	$\frac{1}{L_{d/q}s+r}$

矢量控制 — 电流前馈



$$\Delta U_d = -L_q I_q 2\pi p f_r$$

$$\Delta U_q = (k_E + L_d I_d) 2\pi p f_r$$

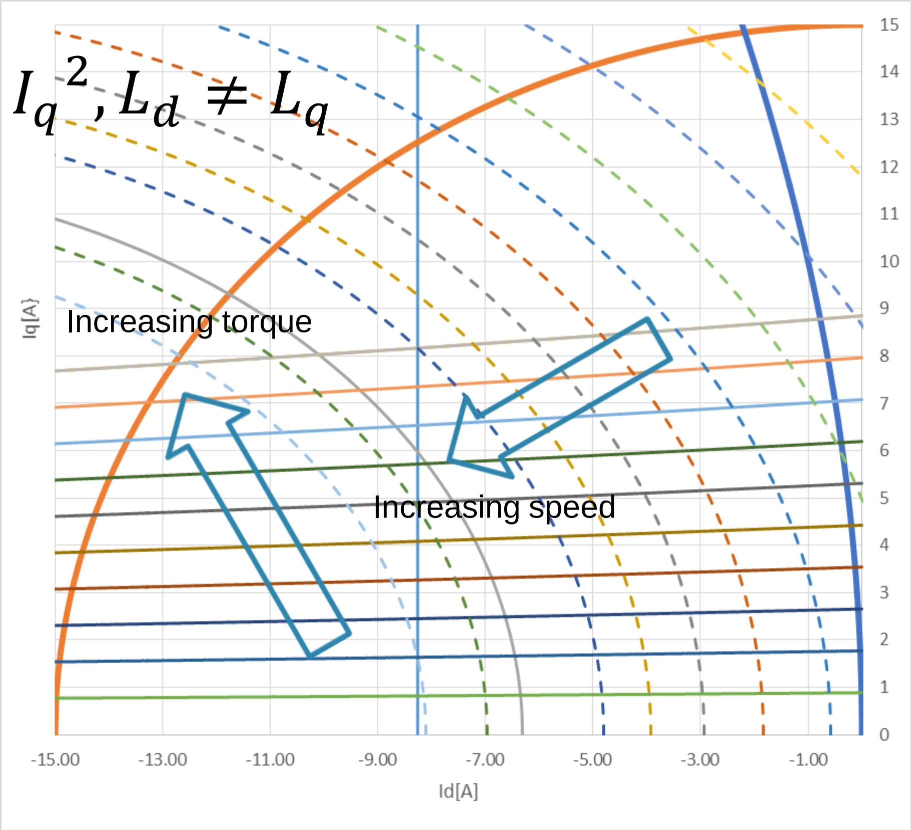


矢量控制 — MTPA与弱磁控制

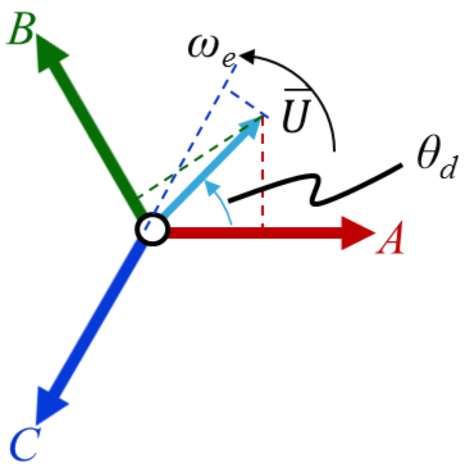
$$\text{MTPA:}I_d = \begin{cases} -\frac{k_E}{2(L_d-L_q)} + sign(L_d - L_q)\sqrt{\left(\frac{k_E}{2(L_d-L_q)}\right)^2 + {I_q}^2}, L_d \neq L_q \\ 0, L_d = L_q \end{cases}$$

$$sign(x) = \begin{cases} 1, x > 0 \\ 0, x = 0 \\ -1, x < 0 \end{cases}$$

$$\text{弱磁: } I_d = \begin{cases} -\frac{k_E}{L_d} + \frac{\sqrt{\left(\frac{U_{1-limit}}{\omega_e}\right)^2 - (L_q I_q)^2}}{L_d}, \frac{U_{1-limit}}{\omega_e} \geq L_q I_d \\ n/a, \frac{U_{1-limit}}{\omega_e} < L_q I_d \end{cases}$$

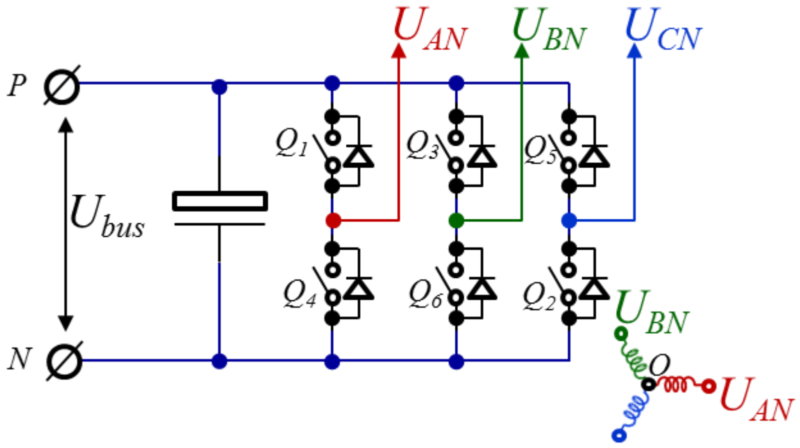


矢量控制 — SVPWM(1/3)



$$U_{AO} = U_m\, cos(\theta_d) = U_m\, cos(\omega_e t)$$
$$U_{BO} = U_m\, cos(\theta_d - 120°) = U_m\, cos(\omega_e t - 120°)$$
$$U_{CO} = U_m\, cos(\theta_d + 120°) = U_m\, cos(\omega_e t + 120°)$$

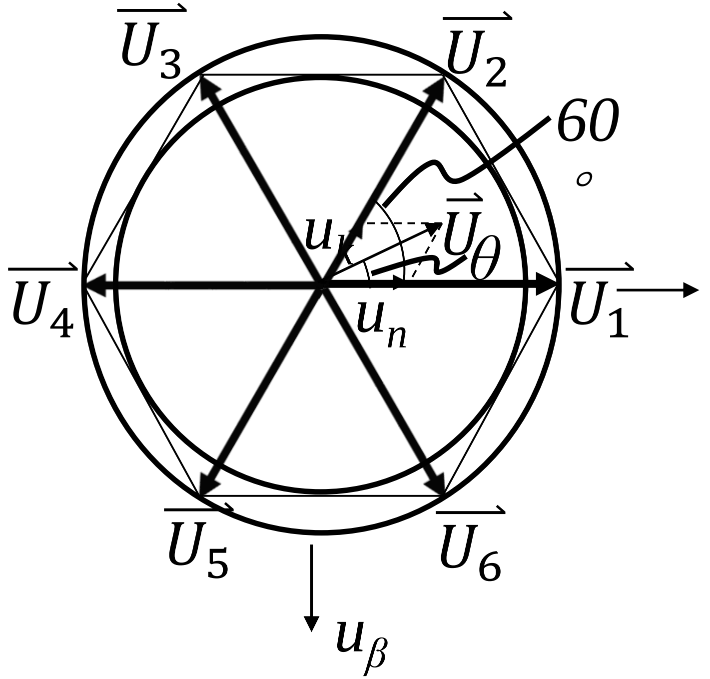
$$|\vec{U}| = U_m$$



uector	$Q_1(Q_4)$	$Q_3(Q_6)$	$Q_5(Q_2)$	U_{AN} [u]	U_{BN}[u]	U_{CN}[u]	U_{AO} [u]	U_{BO}[u]	U_{CO}[u]
$\vec{U_0}$	OFF(ON)	OFF(ON)	OFF(ON)	0	0	0	0	0	0
$\vec{U_1}$	ON(OFF)	OFF(ON)	OFF(ON)	U_{bus}	0	0	$2U_{bus}/3$	$-U_{bus}/3$	$-U_{bus}/3$
$\vec{U_2}$	ON(OFF)	ON(OFF)	OFF(ON)	U_{bus}	U_{bus}	0	$U_{bus}/3$	$U_{bus}/3$	$-2U_{bus}/3$
$\vec{U_3}$	OFF(ON)	ON(OFF)	OFF(ON)	0	U_{bus}	0	$-U_{bus}/3$	$2U_{bus}/3$	$-U_{bus}/3$
$\vec{U_4}$	OFF(ON)	ON(OFF)	ON(OFF)	0	U_{bus}	U_{bus}	$-2U_{bus}/3$	$U_{bus}/3$	$U_{bus}/3$
$\vec{U_5}$	OFF(ON)	OFF(ON)	ON(OFF)	0	0	U_{bus}	$-U_{bus}/3$	$-U_{bus}/3$	$2U_{bus}/3$
$\vec{U_6}$	ON(OFF)	OFF(ON)	ON(OFF)	U_{bus}	0	U_{bus}	$U_{bus}/3$	$-2U_{bus}/3$	$-U_{bus}/3$
$\vec{U_7}$	ON(OFF)	ON(OFF)	ON(OFF)	U_{bus}	U_{bus}	U_{bus}	0	0	0

life.augmented

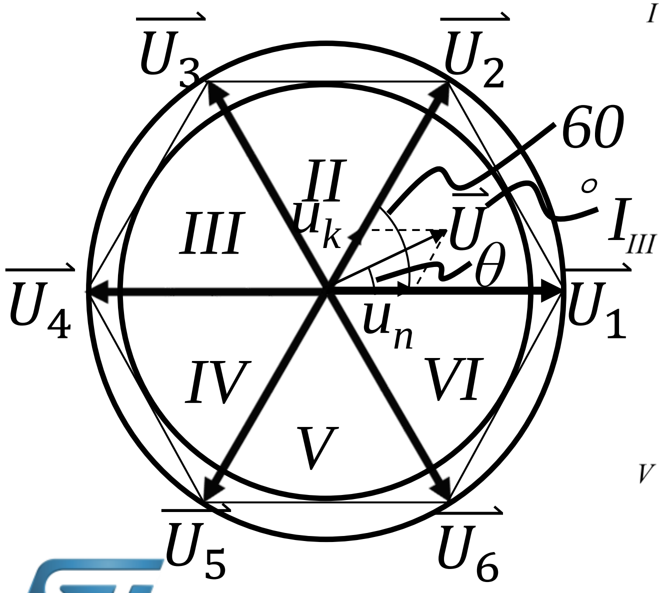
矢量控制 — SVPWM(2/3)

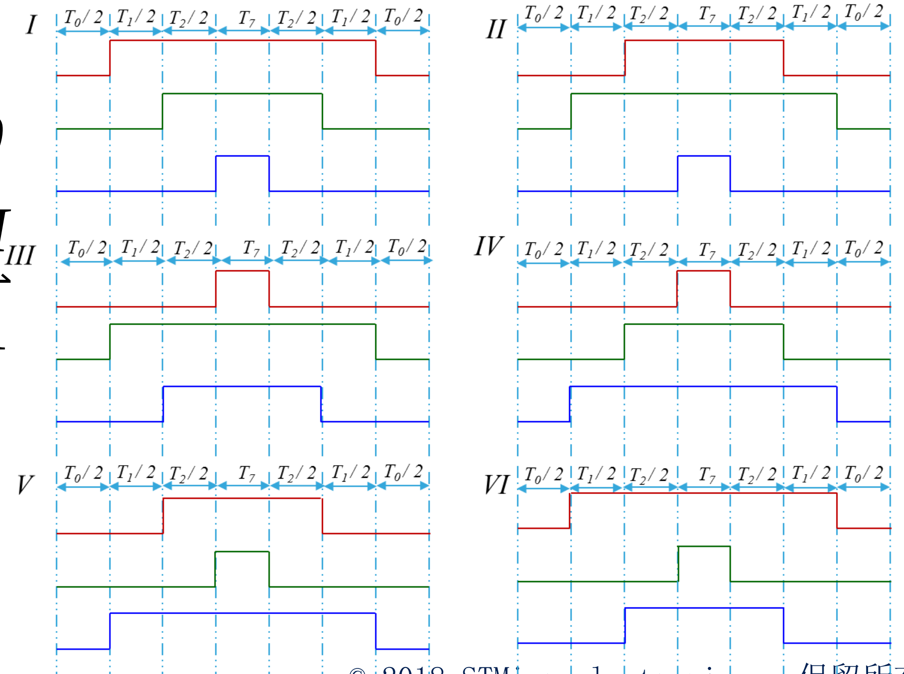


$$\begin{cases} \vec{U}T = T_1\vec{U_n} + T_2\vec{U_k} \\ T \geq T_1 + T_2 \end{cases}$$

Sector	*I*	*II*	*III*	*IV*	*V*	*VI*
n	1	3	3	5	5	1
k	2	2	4	4	6	6

$$\frac{|\vec{U}|}{\sin(180° - 60°)} = \frac{u_{n\ or\ k}}{\sin(60° - \theta)} = \frac{u_{k\ or\ n}}{\sin\theta}, 0° \leq \theta \leq 60°$$





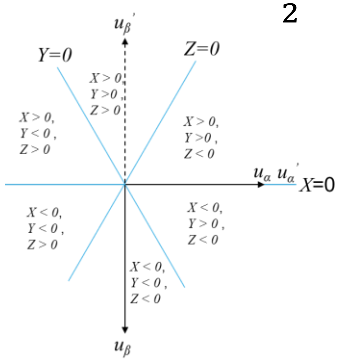
$$T = T_0 + T_1 + T_2 + T_7$$

$$\begin{cases} u_\alpha = |\vec{U}|\cos(60°(sector\ no. -1) + \theta) \\ u_\beta = -|\vec{U}|\sin(60°(sector\ no. -1) + \theta) \end{cases}$$

life.augmented

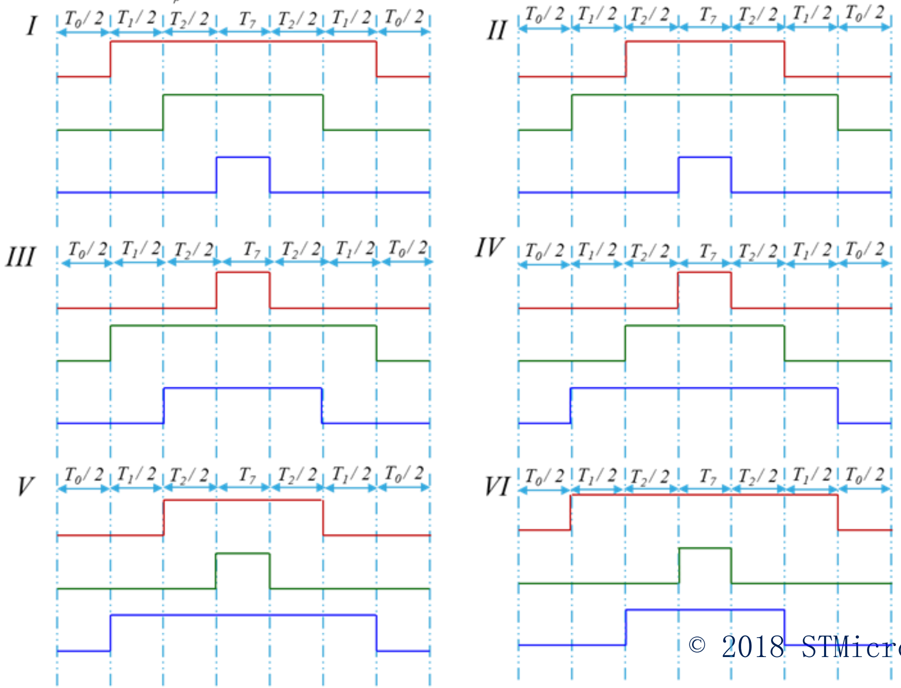
矢量控制 — SVPWM(3/3)

By normalization, if $\overrightarrow{U'} = \frac{\vec{U}}{\frac{\sqrt{3}}{2}}$, because, if $\left|\overrightarrow{U_n}\right| = 1, n = 1,2,3,4,5,6$;then $\left|\vec{U}\right|_{max} = \frac{\sqrt{3}}{2}$,therefore, $\left|\overrightarrow{U'}\right| = 1.$



$$\begin{cases} u_\alpha' = \sqrt{3}u_\alpha T \\ u_\beta' = -u_\beta T \end{cases} \qquad \begin{cases} X = u_\beta' \\ Y = \dfrac{u_\alpha' + u_\beta'}{2} \\ Z = \dfrac{u_\beta' - u_\alpha'}{2} \end{cases}$$

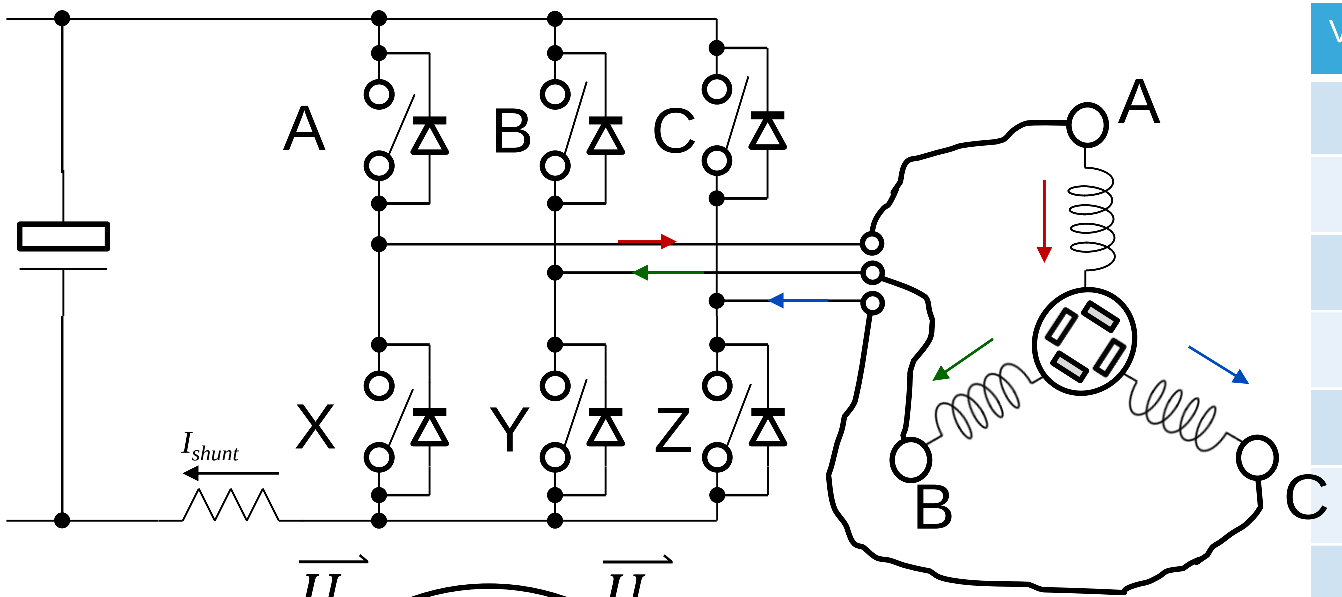
$$\begin{cases} tmax = T_1 + T_2 + \dfrac{T_0 + T_7}{2} \\ tmid = T_2 + \dfrac{T_0 + T_7}{2} = tmax - T_1 \\ tmin = tmid - T_2 \end{cases}$$

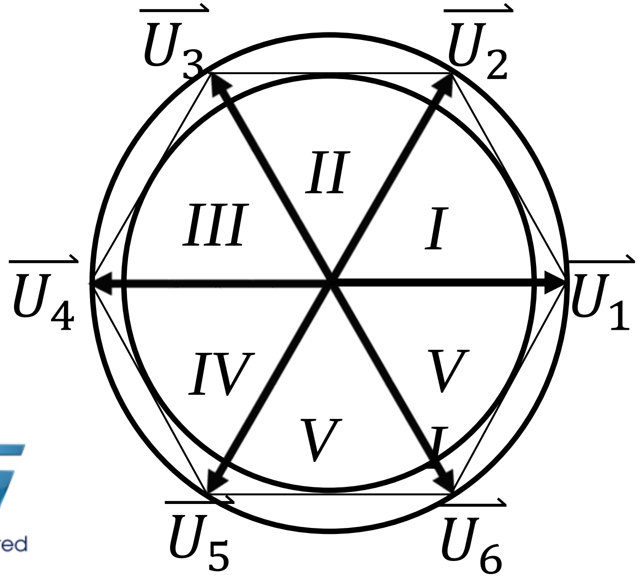


sector	T1	T2	T0+T7
I	-*Z*	*X*	$T+Z-X$
II	*Z*	*Y*	$T-Y-Z$
III	*X*	-*Y*	$T-X+Y$
IV	-*X*	*Z*	$T+X-Z$
V	-*Y*	-*Z*	$T+Y+Z$
VI	*Y*	-*X*	$T+X-Y$

sector	tA	tB	tC
I	*T/2 + (X – Z)/2*	*tA + Z*	*tB – X*
II	*T/2 + (Y – Z)/2*	*tA + Z*	*tA – Y*
III	*T/2 + (Y – X)/2*	*tC + X*	*tA – Y*
IV	*T/2 + (X – Z)/2*	*tA + Z*	*tB – X*
V	*T/2 + (Y – Z)/2*	*tA + Z*	*tA – Y*
VI	*T/2 + (Y – X)/2*	*tC + X*	*tA – Y*

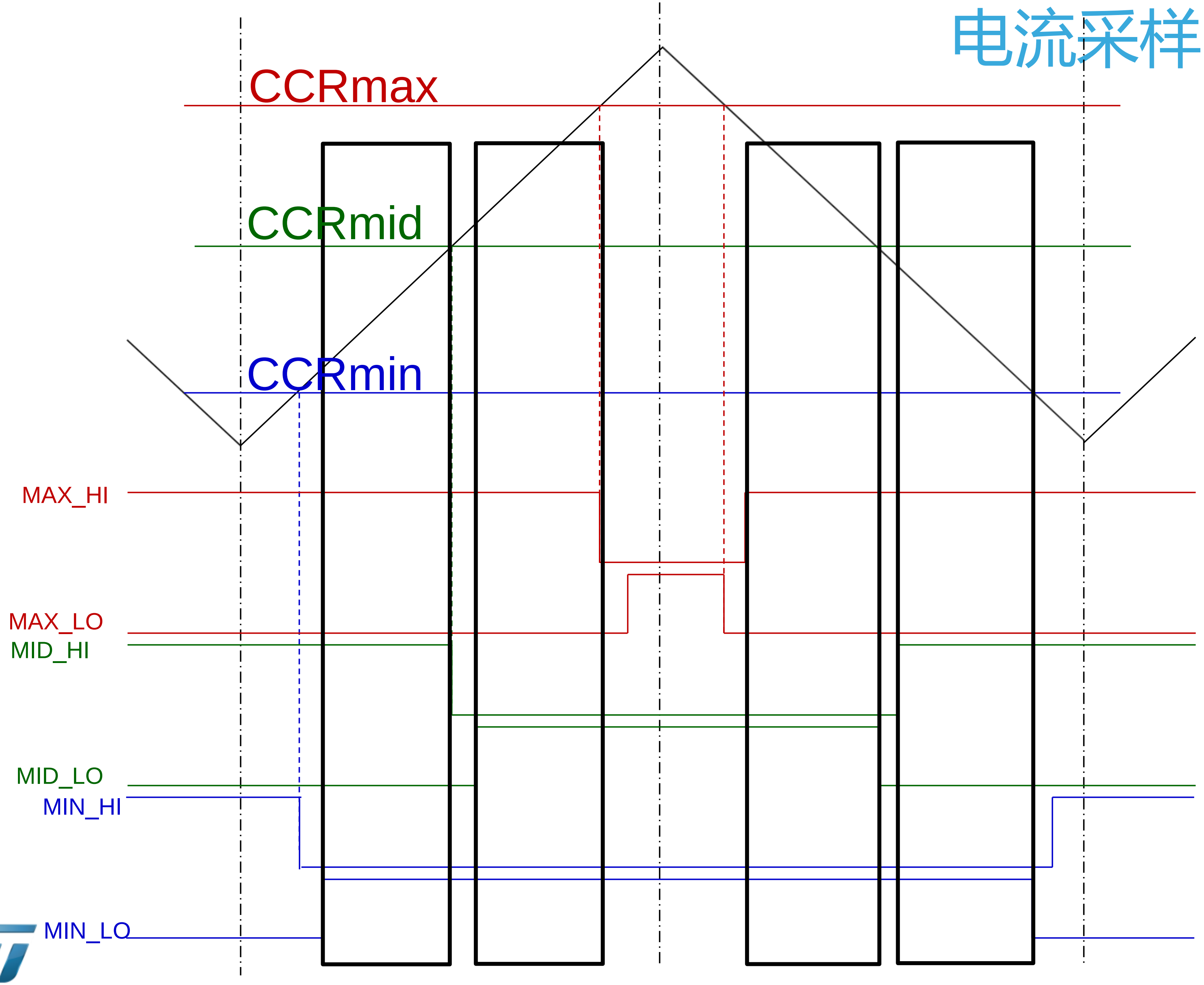
电流采样 — 单电阻(2/8)





Vector	*A(X)*	*B(Y)*	*C(Z)*	*Ishunt*
$\overrightarrow{U_0}$	OFF(ON)	OFF(ON)	OFF(ON)	*0*
$\overrightarrow{U_1}$	ON(OFF)	OFF(ON)	OFF(ON)	i_A
$\overrightarrow{U_2}$	ON(OFF)	ON(OFF)	OFF(ON)	$-i_C$
$\overrightarrow{U_3}$	OFF(ON)	ON(OFF)	OFF(ON)	i_B
$\overrightarrow{U_4}$	OFF(ON)	ON(OFF)	ON(OFF)	$-i_A$
$\overrightarrow{U_5}$	OFF(ON)	OFF(ON)	ON(OFF)	i_C
$\overrightarrow{U_6}$	ON(OFF)	OFF(ON)	ON(OFF)	$-i_B$
$\overrightarrow{U_7}$	ON(OFF)	ON(OFF)	ON(OFF)	*0*

电流采样 — 单电阻(3/8)



if $T_{ADCtrigger\ delay} > T_{ring}$,needless to add Tring available current signal detection pulse width is:

$Min\_pulsewidth = T_{dead} + T_{on} + T_{ADCtrigger\ delay} + T_{ADC\ s/h}$ else, available current signal detection pulse width is:

$Min\_pulsewidth = T_{dead} + T_{on} + T_{ring} + T_{ADC\ s/h}$

ADC trigger point:

Point 1)CCRmid - $T_{ADCtrigger\ delay}$ -$T_{ADC\ s/h}$ -

Point 2)

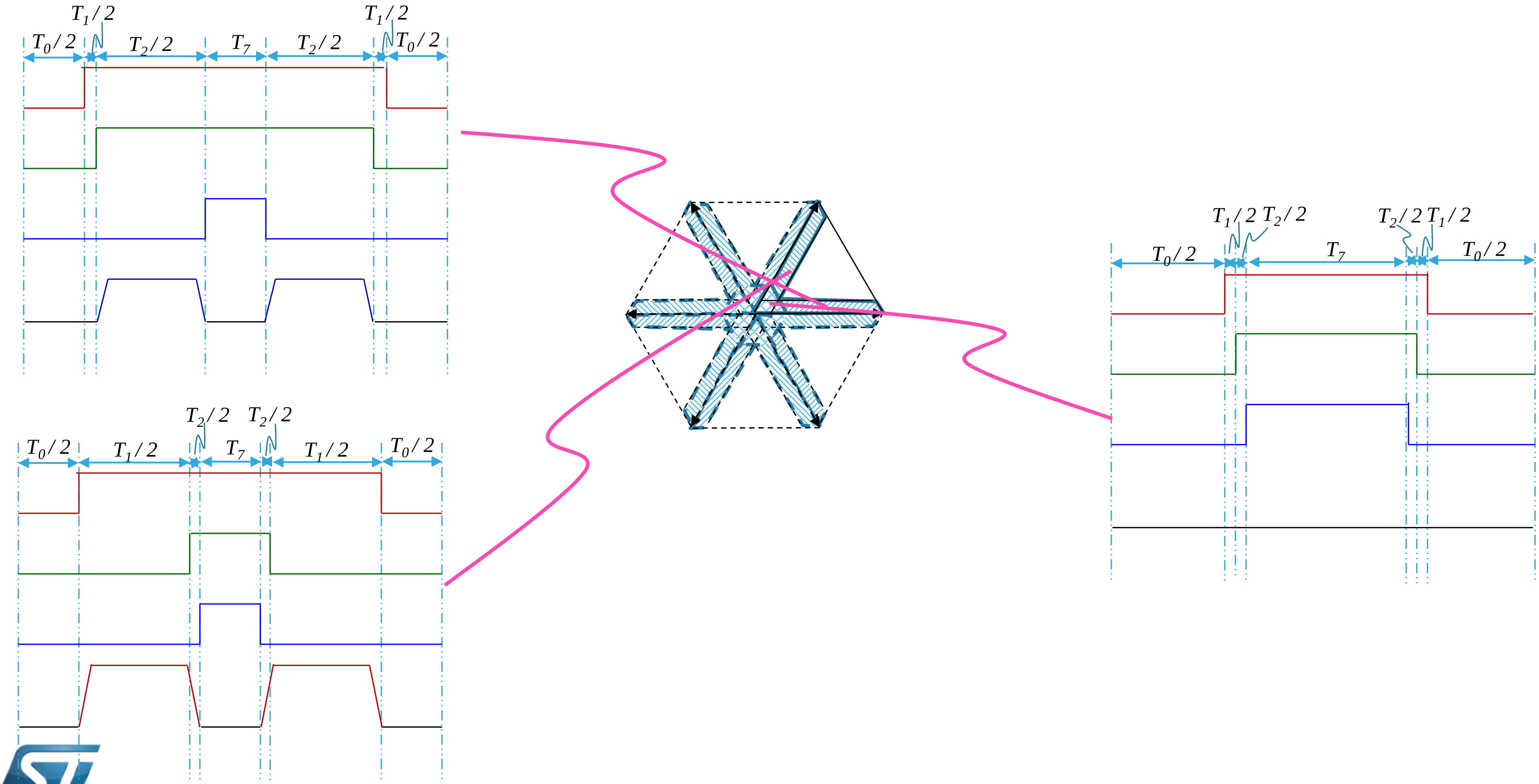
if $T_{ADCtrigger\ delay} > T_{ring}$

CCRmid + $T_{dead} + T_{on} + T_{ring} - T_{ADCtrigger\ delay}$

Else

CCRmid + $T_{dead} + T_{on} + T_{ADCtrigger\ delay}$

电流采样 — 单电阻(4/8)

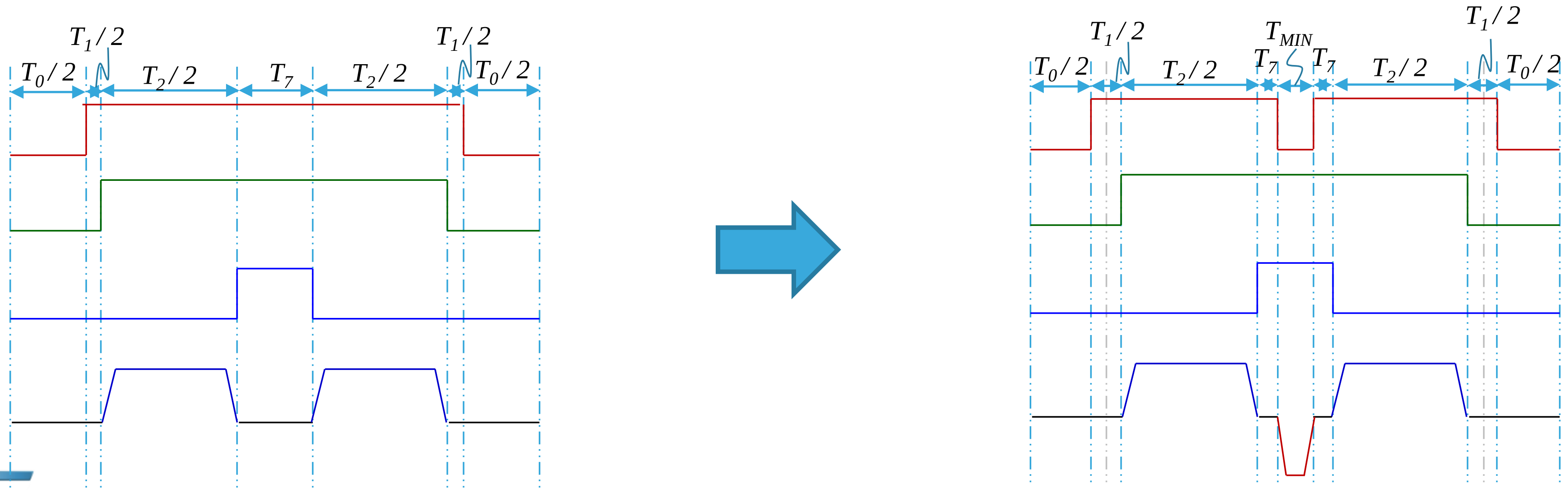


$T_1/2$
$T_0/2$
$T_2/2$
T_7
$T_2/2$
$T_1/2$
$T_0/2$
$T_2/2$ $T_2/2$
$T_0/2$
$T_1/2$
T_7
$T_1/2$
$T_0/2$
$T_1/2$ $T_2/2$
$T_2/2$ $T_1/2$
$T_0/2$
T_7
$T_0/2$

电流采样 — 单电阻(5/8)

ST 专利
US20090284194 A1

ST 专利 (Pat. Pub. No.: US20090284194 A1) 解决单电阻无法采样问题

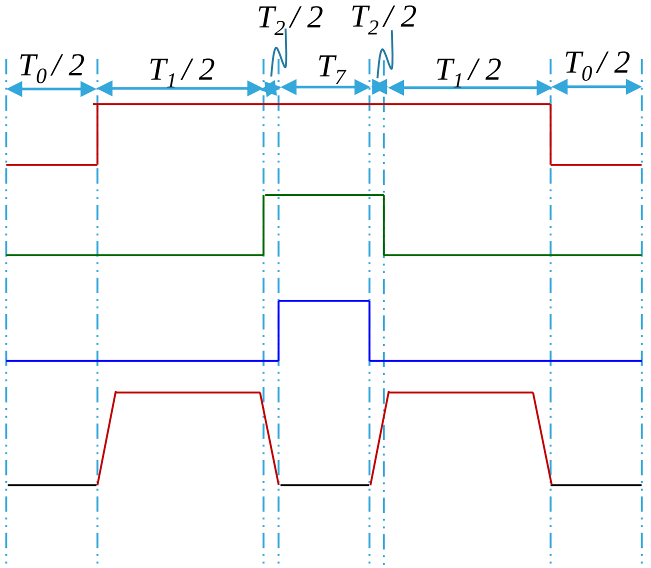


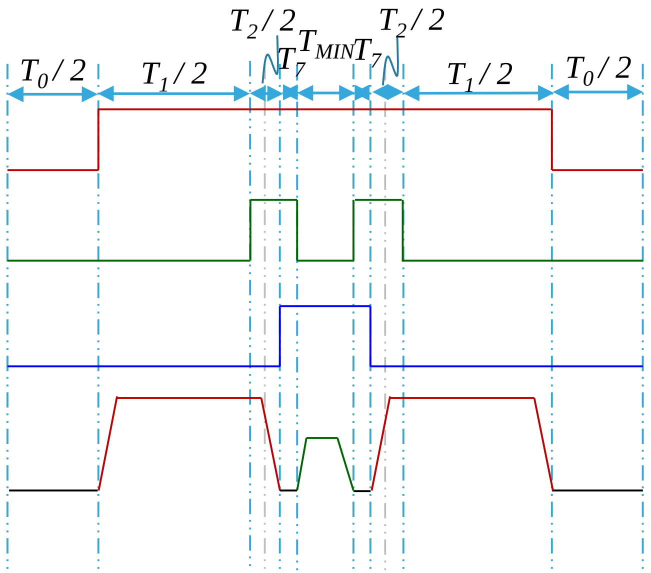
life.augmented

电流采样 — 单电阻(6/8)

ST 专利
US20090284194 A1

ST 专利 (Pat. Pub. No.: US20090284194 A1) 解决单电阻无法采样问题



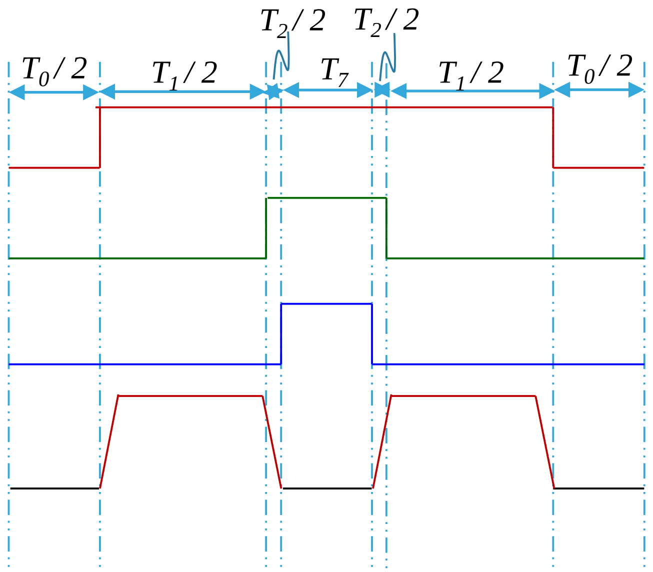


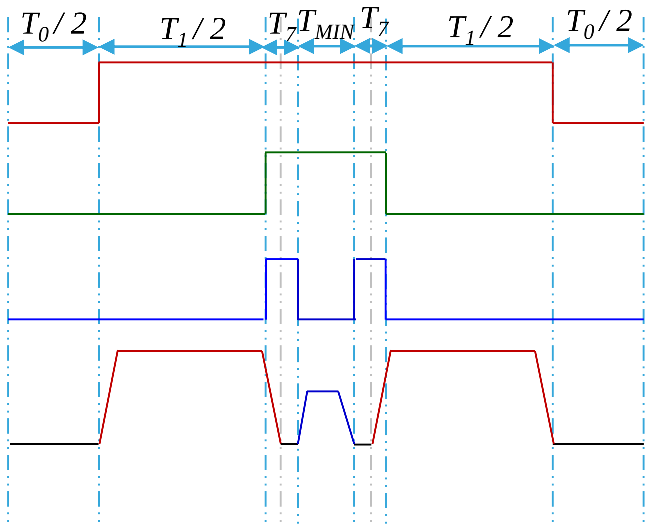
life.augmented

电流采样 — 单电阻(7/8)

ST 专利
US20090284194 A1

ST 专利 (Pat. Pub. No.: US20090284194 A1) 解决单电阻无法采样问题

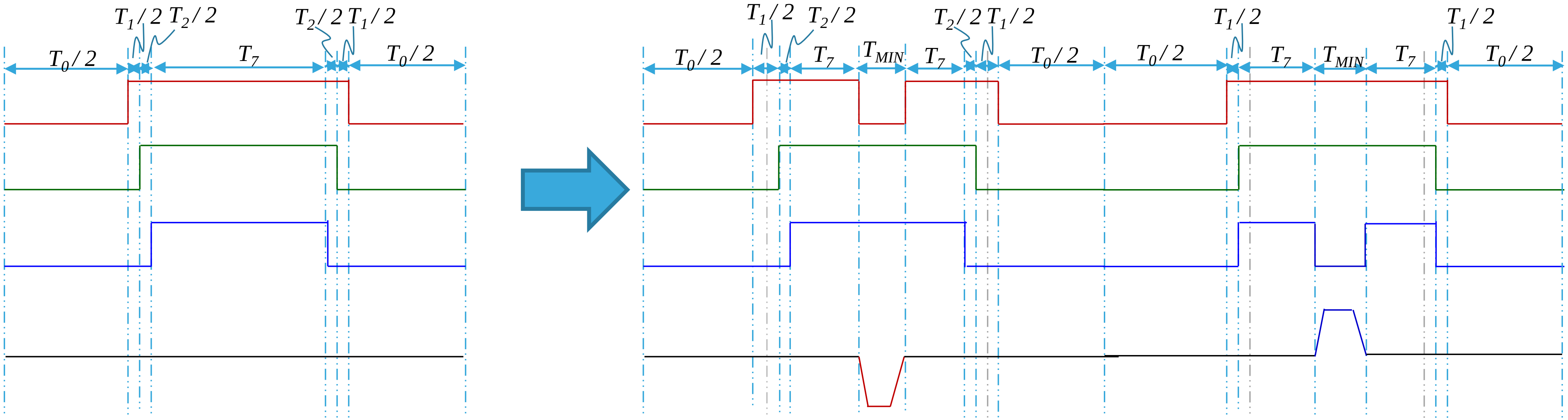




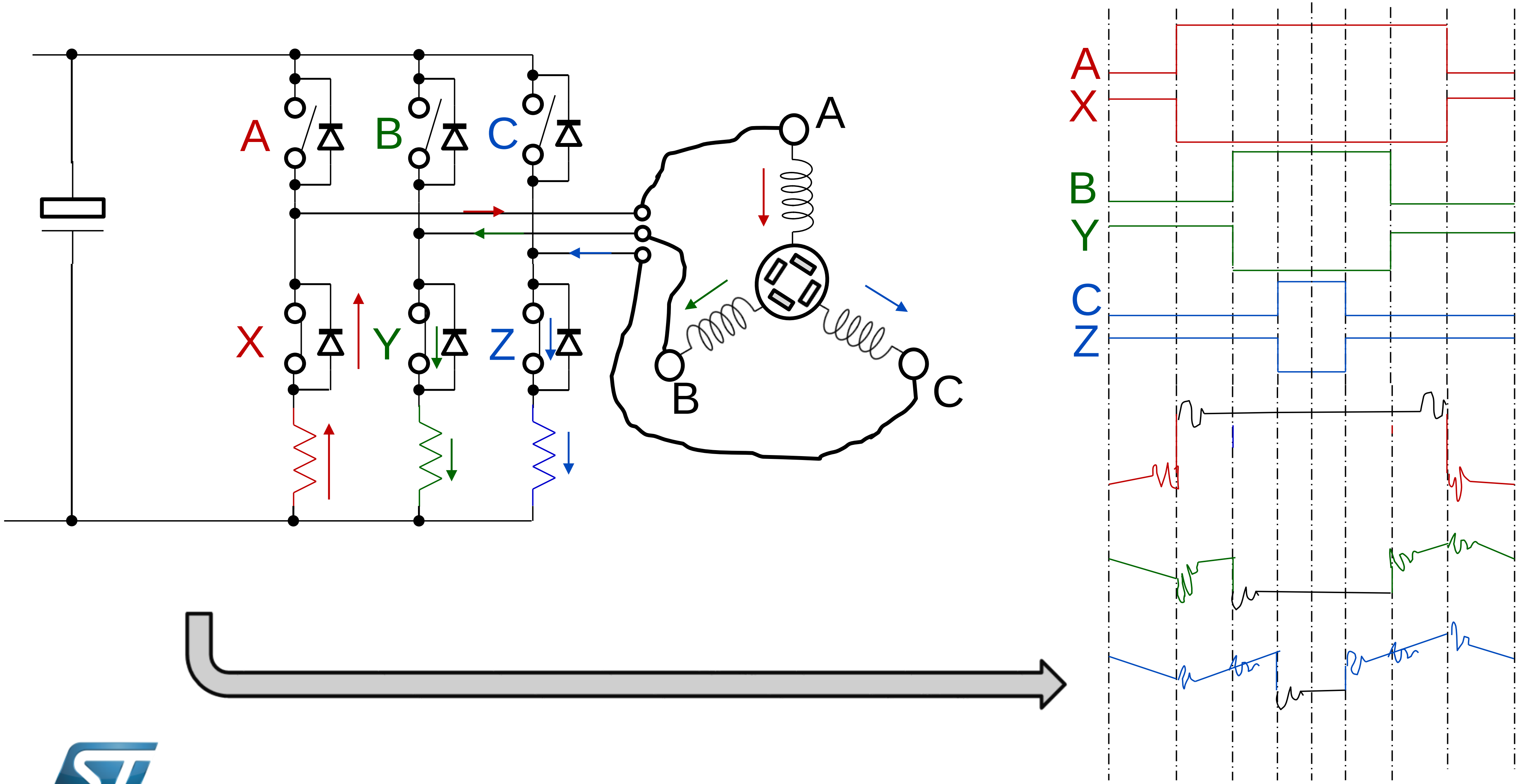
电流采样 — 单电阻(8/8)

ST 专利
US20090284194 A1

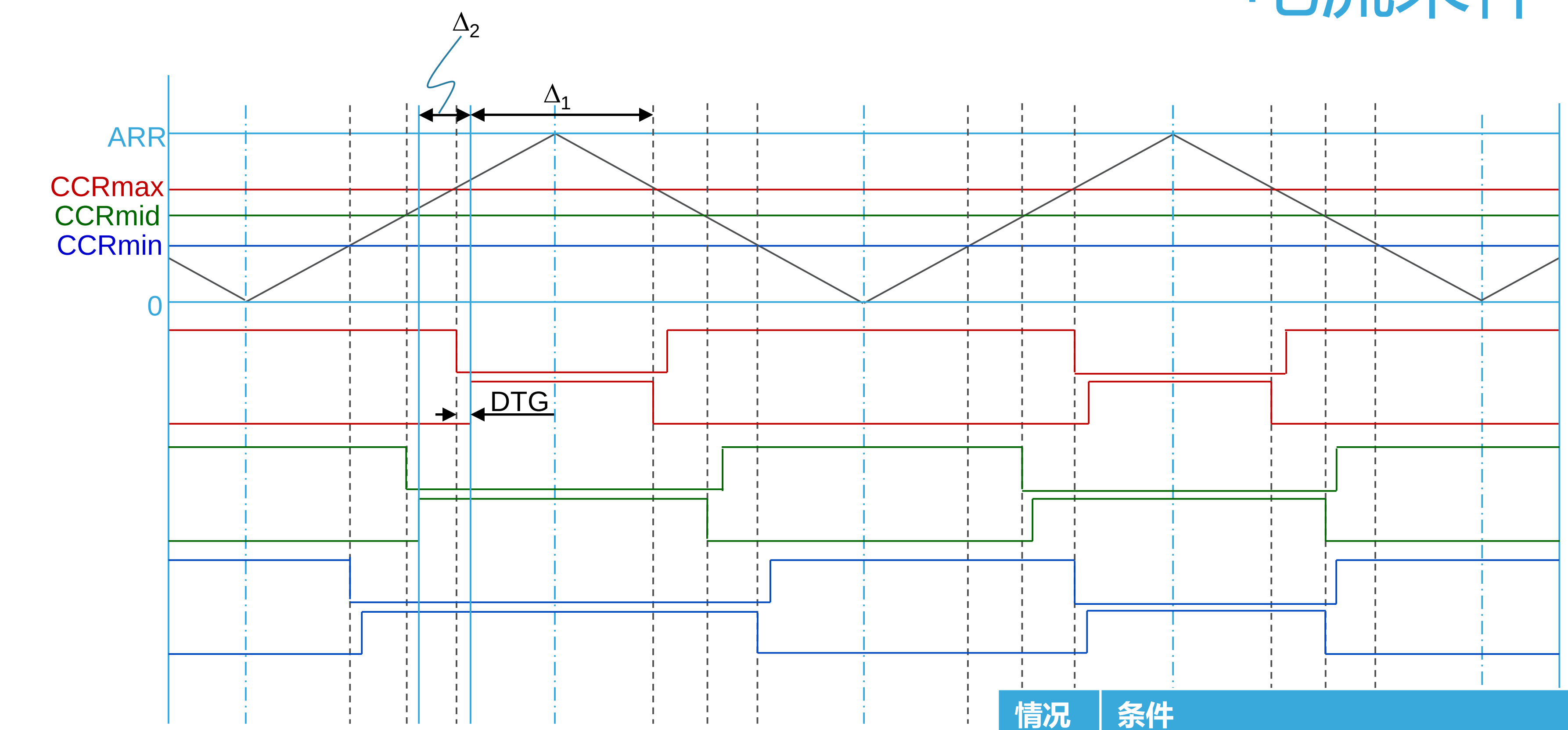
ST 专利 (Pat. Pub. No.: US20090284194 A1) 解决单电阻无法采样问题

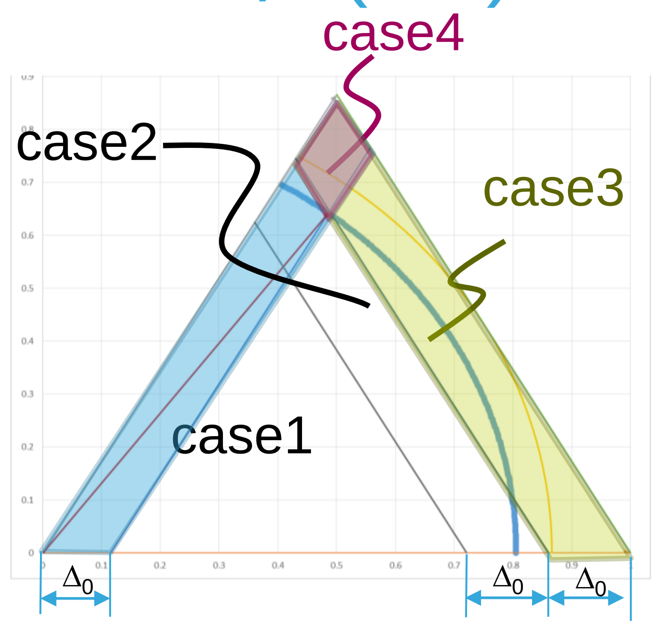


电流采样 — 三电阻(1/2)



电流采样 — 三电阻(2/2)





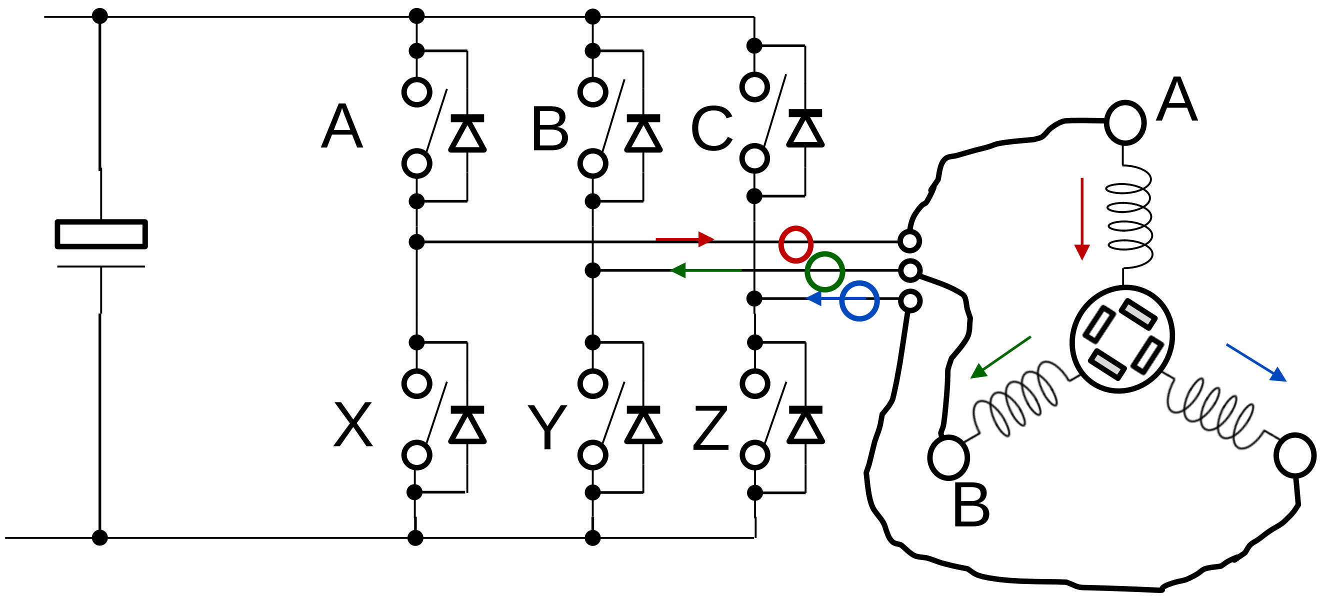
$\Delta_1 = 2*(ARR - CCRmax - DTG)$
$\Delta_2 = CCRmax - CCRmid$

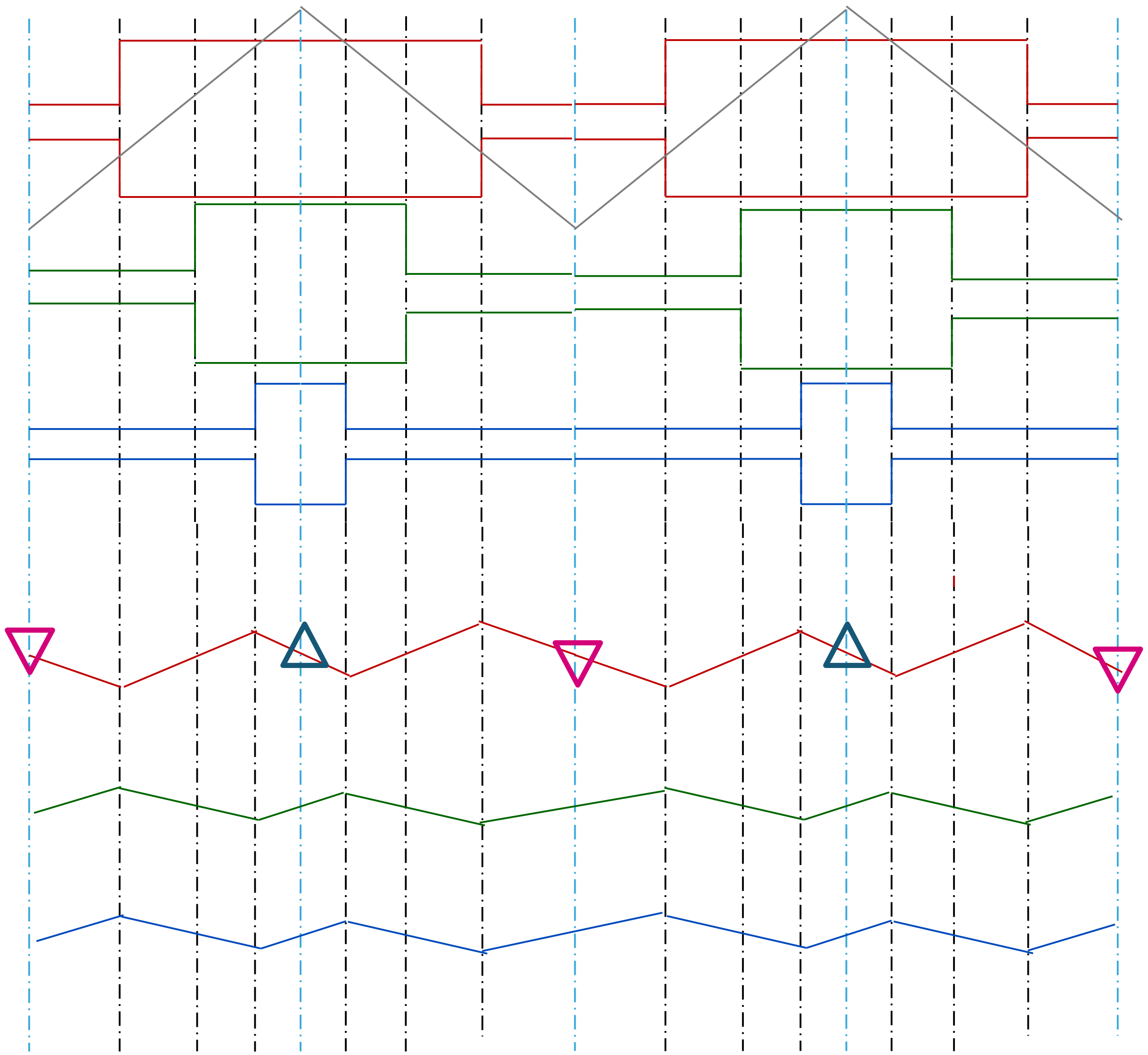
Δ_0 = CNT_Ton+CNT_Trise+CNT_Ring+CNT_TADCSH(COV) ,
Tring > TADCsta
Δ_0 = CNT_Ton+CNT_Trise +CNT_TADCsta+CNT_TADCSH(COV),
TADCsta>=Tring

情况	条件	采样点
1	Δ_1 >max(2*(CNT_Ton+CNT_Trise+CNT_Ring+tdead/2) , CNT_TADCsta+CNT_TADCSH(COV)-tdead/2)	Middle of PWM
2	$\Delta_1 > \Delta_0$	CCRmax+ tdead+ton+tring+ε
3	$\Delta_2 > \Delta_0 > \Delta_1$	CCRmid + tdead+ton+tring+ε
4	$\Delta_1 < \Delta_0$ and $\Delta_2 < \Delta_0$	Not available

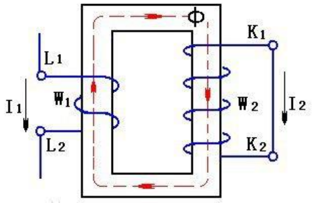
life.augmented

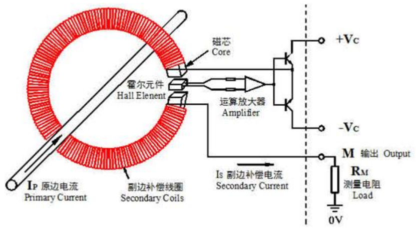
电流采样 — ICS





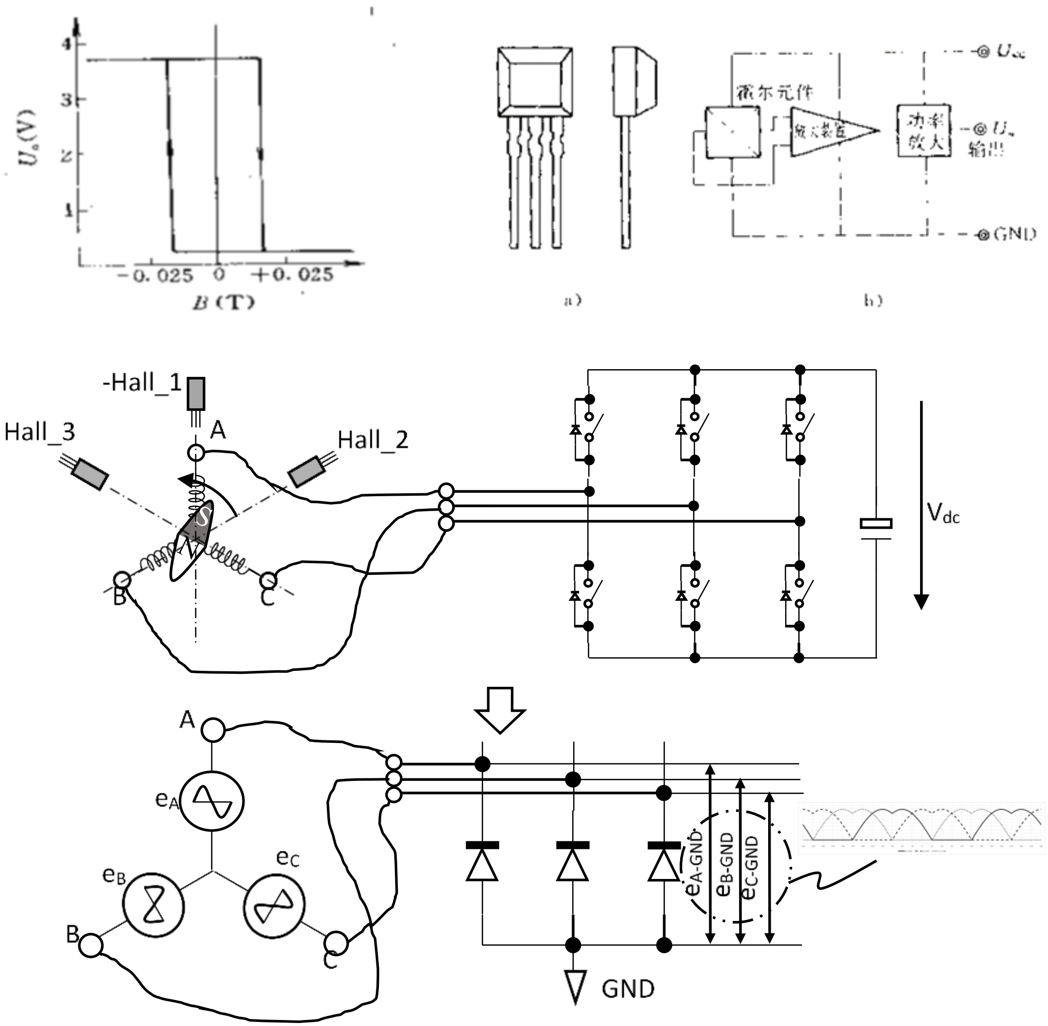
	ACCT	DCCT
频率范围	>0 Hz ~ tens kHz	DC ~ 100kHz
退磁	Need	Need not
成本	low	High

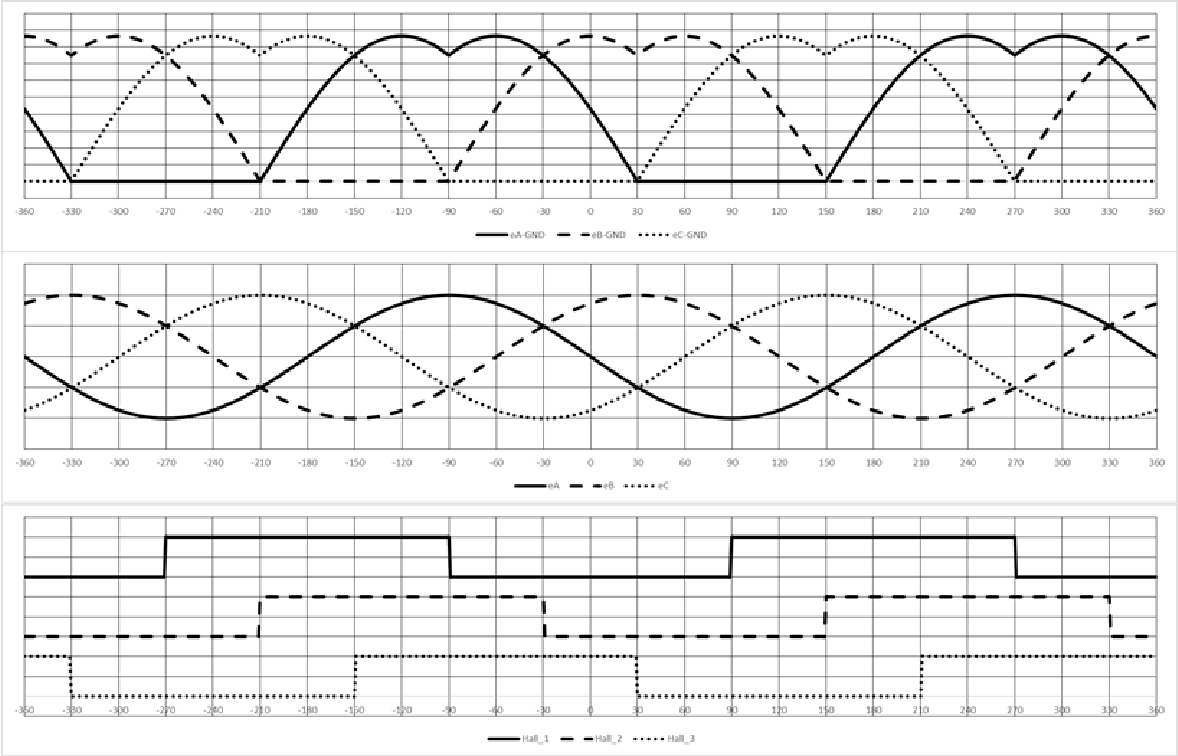




life.augmented

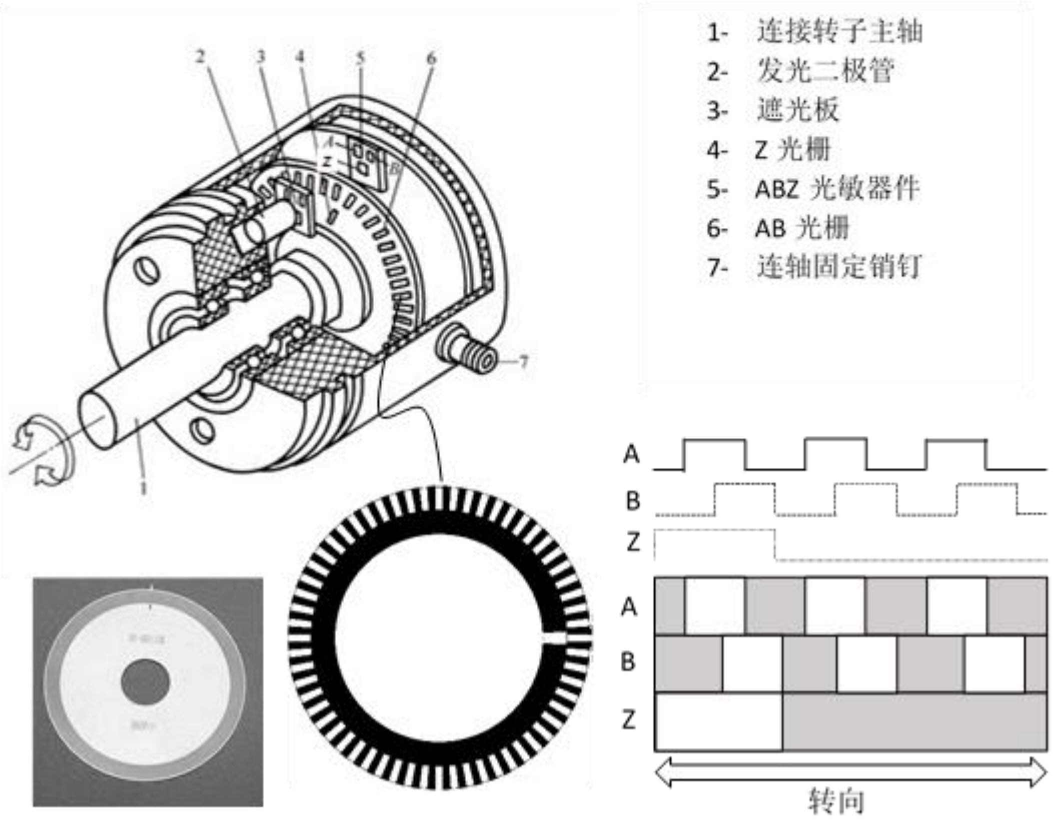
位置速度检测 — Hall传感器

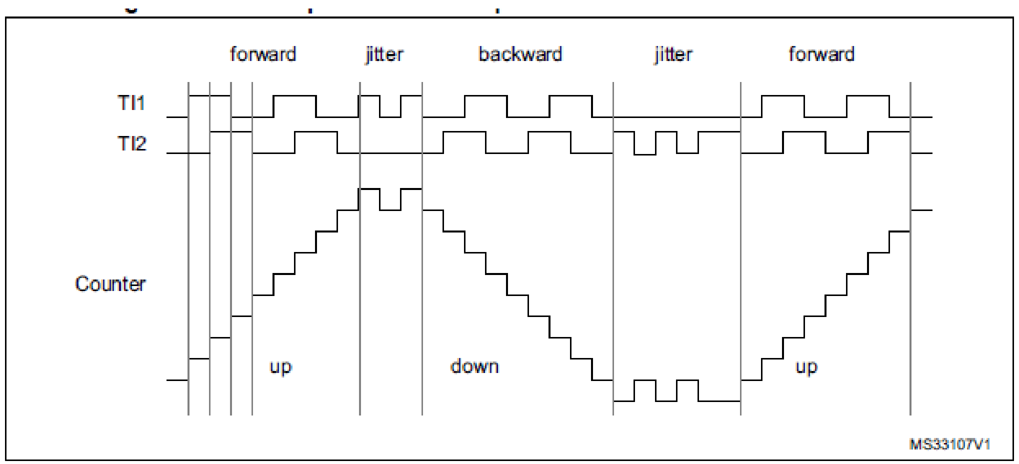




对于60度的Hall信号，可以任意调换三个信号中的任意一个即可得到和120度的处理相似，我们可以很方便使用软件处理。

位置速度检测 — Encoder

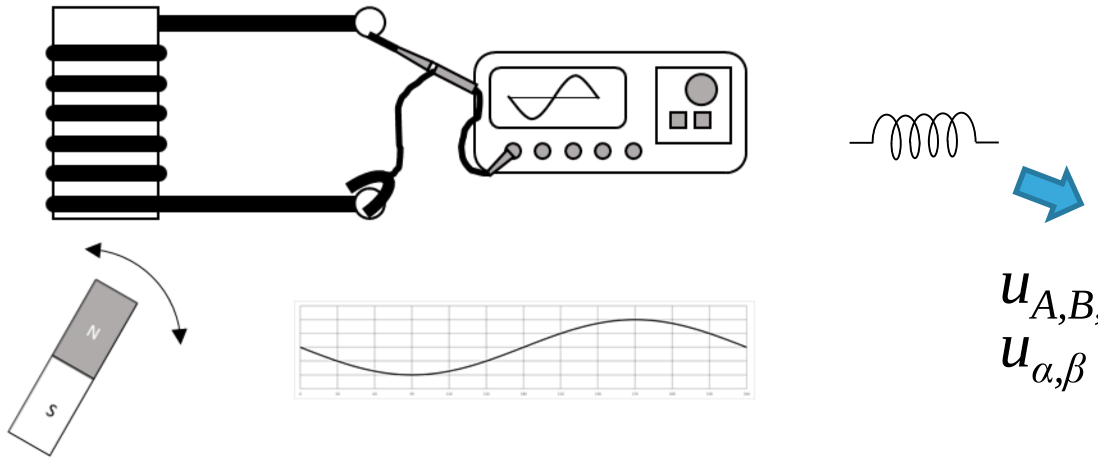


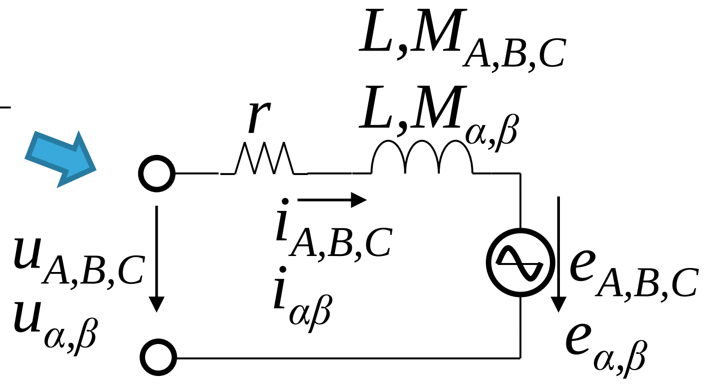


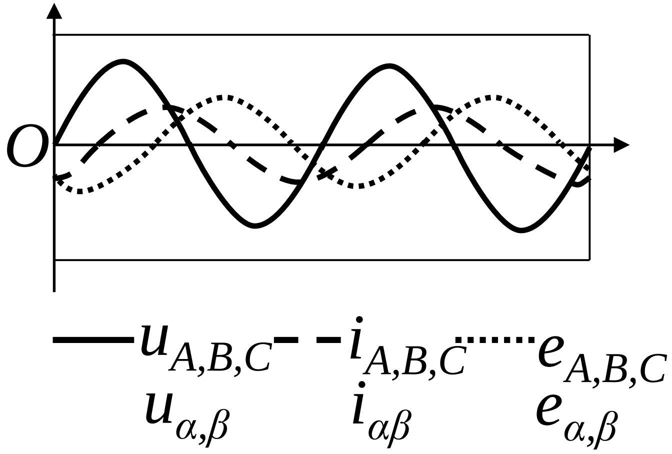
使用增量编码器时，在第一次电机启动，任意保护停止或者MCU复位后都要进行预定位操作。

Z信号（一圈一个）可以使用外部中断或者外部Timer捕捉模式，代表编码器的0度位置，可以用于校准角度位置，可以使用DMA模式对编码器模块赋值；

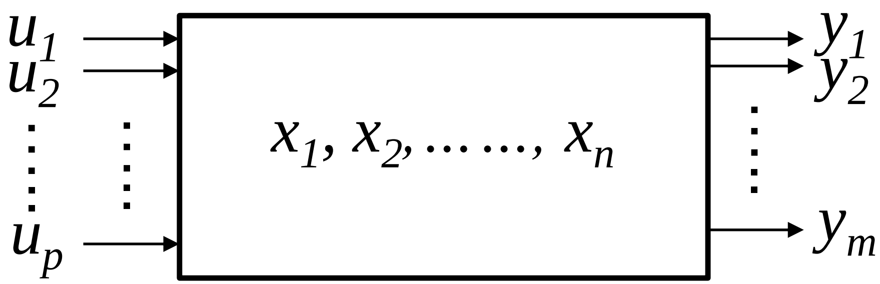
位置速度检测 — 观测器(1/11)

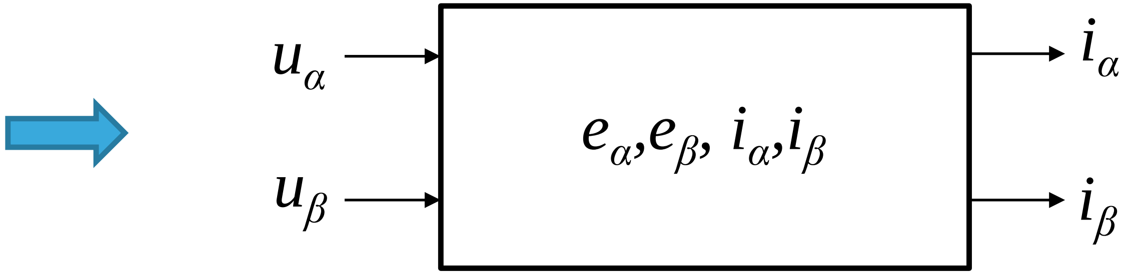




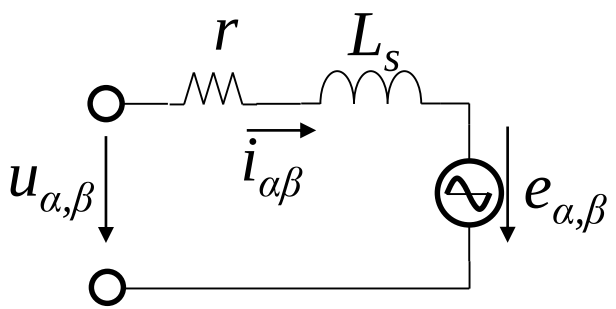


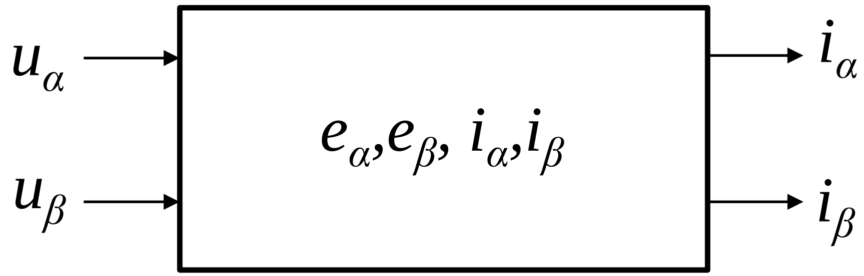
$$u \text{ -> } i\ (\tau_e) \text{ -> } \omega_r, \omega_e = p \cdot \omega_r \text{ - > } e$$

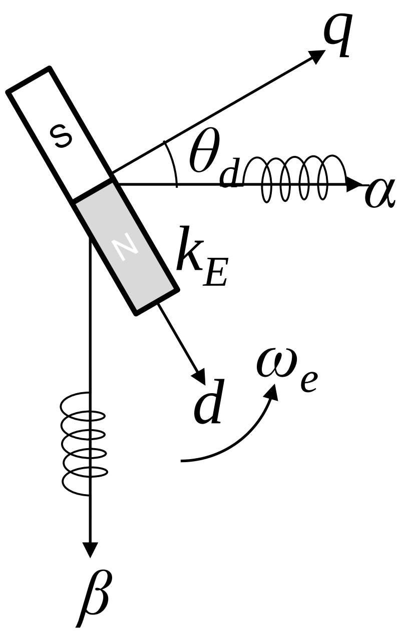




位置速度检测 — 观测器(2/11)





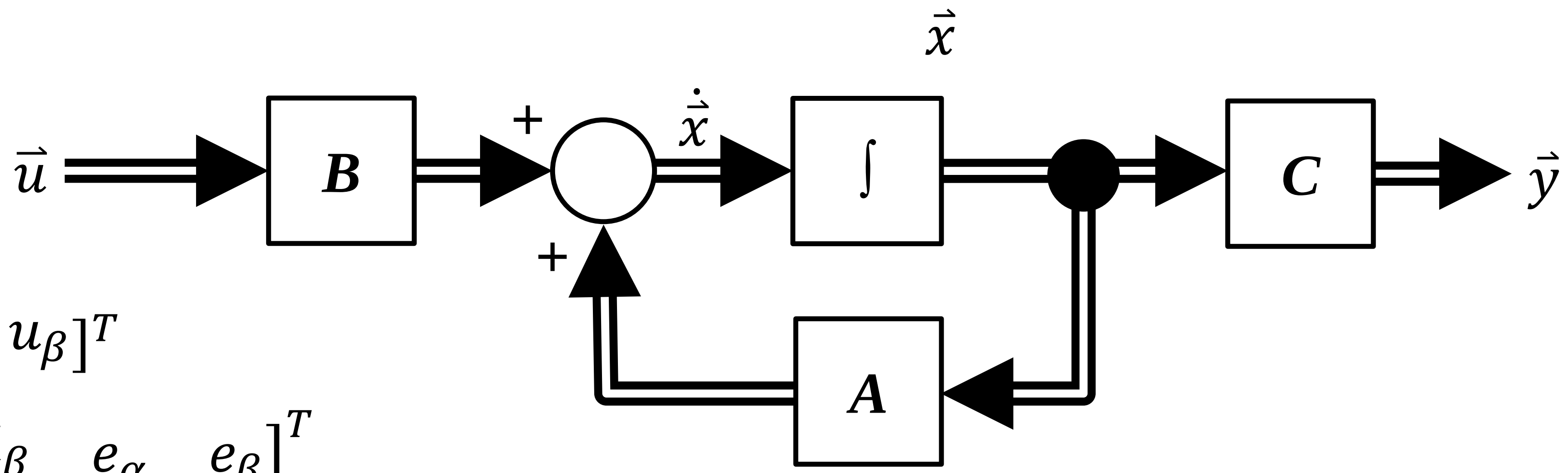


$$\begin{cases} e_\alpha = \dfrac{dk_E \sin\theta_d}{dt} = \dfrac{dk_E \sin(\theta_{d0}+\omega_e t)}{dt} \\ e_\beta = \dfrac{dk_E \cos\theta_d}{dt} = \dfrac{dk_E \cos(\theta_{d0}+\omega_e t)}{dt} \end{cases}$$

A linear model

$$\begin{cases} \dfrac{di_\alpha}{dt} = -\dfrac{r}{L_s} i_\alpha - \dfrac{e_\alpha}{L_s} + \dfrac{u_\alpha}{L_s} \\ \dfrac{di_\beta}{dt} = -\dfrac{r}{L_s} i_\beta - \dfrac{e_\beta}{L_s} + \dfrac{u_\beta}{L_s} \\ \dfrac{de_\alpha}{dt} = \omega_e e_\beta \\ \dfrac{de_\beta}{dt} = -\omega_e e_\alpha \end{cases}$$

life.augmented



$$\vec{u} = [u_\alpha \quad u_\beta]^T$$

$$\vec{x} = \begin{bmatrix} i_\alpha & i_\beta & e_\alpha & e_\beta \end{bmatrix}^T$$

$$\dot{\vec{x}} = \begin{bmatrix} \frac{di_\alpha}{dt} & \frac{di_\beta}{dt} & \frac{de_\alpha}{dt} & \frac{de_\beta}{dt} \end{bmatrix}^T$$

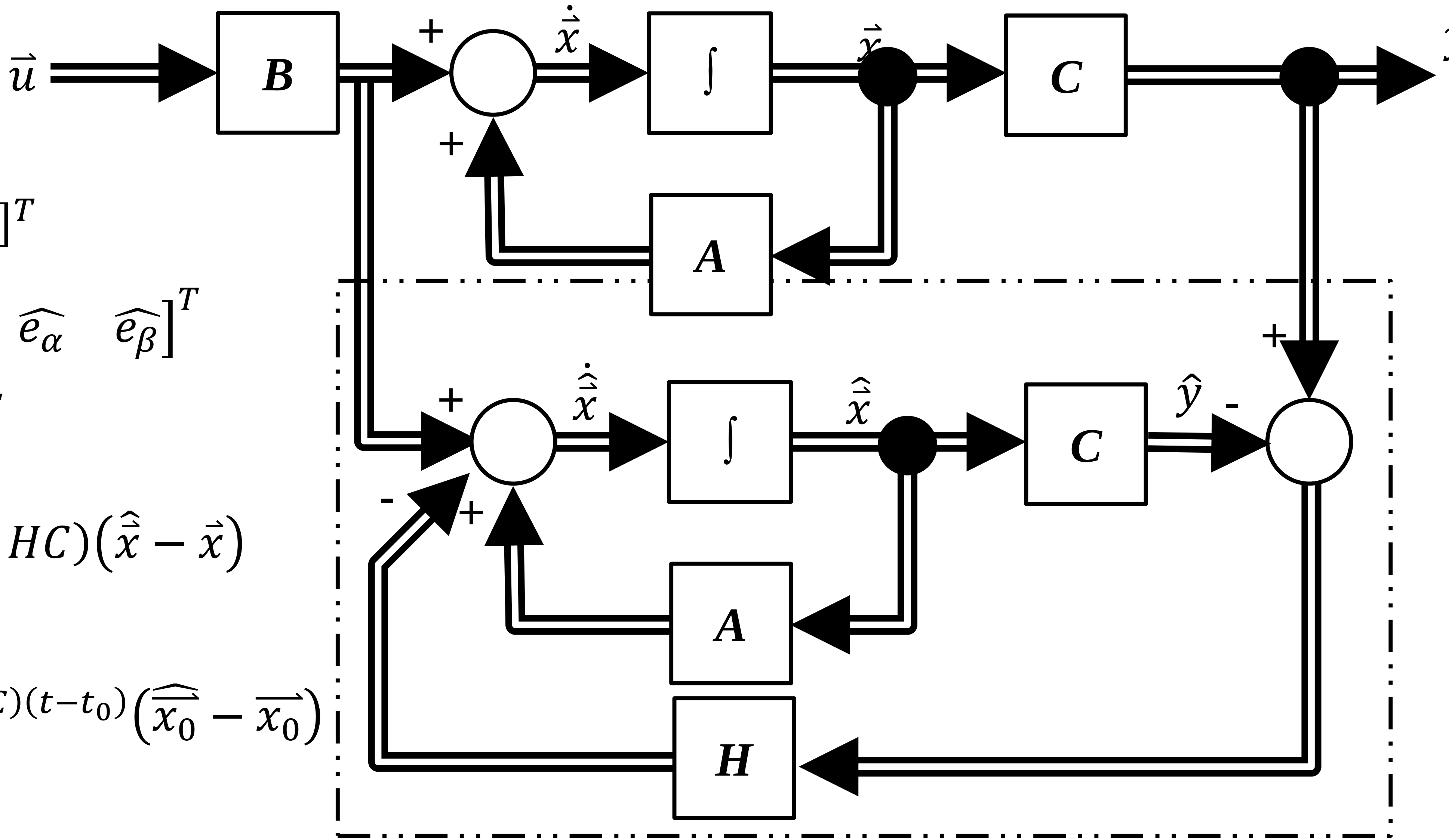
$$\vec{y} = [i_\alpha \quad i_\beta]^T$$

$$\begin{cases} \dot{\vec{x}} = A\vec{x} + B\vec{u} \\ \vec{y} = C\vec{x} \end{cases}$$

$$A = \begin{bmatrix} -\frac{r}{L_s} & 0 & -\frac{1}{L_s} & 0 \\ 0 & -\frac{r}{L_s} & 0 & -\frac{1}{L_s} \\ 0 & 0 & 0 & \omega_e \\ 0 & 0 & -\omega_e & 0 \end{bmatrix} \quad B = \begin{bmatrix} -\frac{1}{L_s} & 0 \\ 0 & -\frac{1}{L_s} \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

位置速度检测 — 观测器(4/11)



$$\vec{u} = [u_\alpha \quad u_\beta]^T$$

$$\hat{\vec{x}} = [\hat{i_\alpha} \quad \hat{i_\beta} \quad \hat{e_\alpha} \quad \hat{e_\beta}]^T$$

$$\hat{y} = [\hat{i_\alpha} \quad \hat{i_\beta}]^T$$

$$\dot{\hat{\vec{x}}} - \dot{\vec{x}} = (A + HC)(\hat{\vec{x}} - \vec{x})$$

$$\hat{\vec{x}} - \vec{x} = e^{(A+HC)(t-t_0)}(\widehat{\vec{x_0}} - \vec{x_0})$$

位置速度检测 — 观测器(5/11)

$$\begin{cases} \dot{\vec{x}} = A\vec{x} + B\vec{u} \\ \vec{y} = C\vec{x} \end{cases} \xrightarrow{\text{离散化}} \begin{cases} \dfrac{\vec{x}[k] - \vec{x}[k-1]}{T_s} = A\vec{x}[k-1] + B\vec{u}[k-1] \\ \vec{y}[k] = C\vec{x}[k] \end{cases}$$

$$\dot{\vec{x}} = \frac{d\vec{x}}{dt} \approx \frac{\vec{x}[k] - \vec{x}[k-1]}{T_s}$$

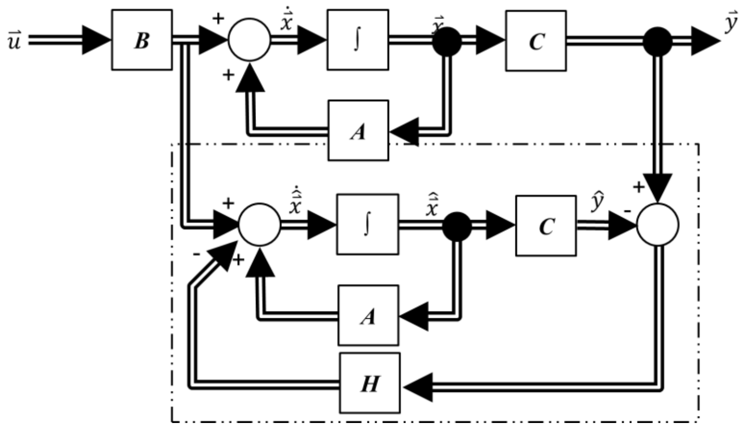
$$\begin{cases} i_\alpha[k] = \left(1 - \dfrac{rT_s}{L_s}\right) i_\alpha[k-1] - \dfrac{T_s}{L_s} e_\alpha[k-1] + \dfrac{T_s}{L_s} u_\alpha \\ i_\beta[k] = \left(1 - \dfrac{rT_s}{L_s}\right) i_\beta[k-1] - \dfrac{T_s}{L_s} e_\beta[k-1] + \dfrac{T_s}{L_s} u_\beta \\ e_\alpha[k] = e_\alpha[k-1] + \omega_e e_\beta[k-1] T_s \\ e_\beta[k] = e_\beta[k-1] - \omega_e e_\alpha[k-1] T_s \end{cases}$$

去耦(认为ω_e=0) 将简化马达模型

$$\begin{cases} i_\alpha[k] = \left(1 - \frac{rT_s}{L_s}\right) i_\alpha[k-1] - \frac{T_s}{L_s} e_\alpha[k-1] + \frac{T_s}{L_s} u_\alpha \\ e_\alpha[k] = e_\alpha[k-1] \end{cases}$$

$$A_{reduced} = \begin{bmatrix} 1 - \frac{rT_s}{L_s} & -\frac{T_s}{L_s} \\ 0 & 1 \end{bmatrix} \xrightarrow[|\lambda I - A| = 0]{\text{特征值}} \begin{cases} \lambda_1 = 1 - \frac{rT_s}{L_s} \\ \lambda_2 = 1 \end{cases}$$

位置速度检测 — 观测器(7/11)



$$\dot{\hat{\vec{x}}} = A\hat{\vec{x}} + B\vec{u} + H\left(\hat{\vec{y}} - \vec{y}\right) \qquad H = \begin{bmatrix} h_1 & 0 \\ 0 & h_1 \\ h_2 & 0 \\ 0 & h_2 \end{bmatrix}$$

$$\begin{cases} \widehat{i_\alpha}[k] = \left(1 - \dfrac{rT_s}{L_s} + h_1 T_s\right)\widehat{i_\alpha}[k-1] - \dfrac{T_s}{L_s}\widehat{e_\alpha}[k-1] + \dfrac{T_s}{L_s}u_\alpha[k-1] + h_1 T_s\left(-i_\alpha[k-1]\right) \\ \widehat{i_\beta}[k] = \left(1 - \dfrac{rT_s}{L_s} + h_1 T_s\right)\widehat{i_\beta}[k-1] - \dfrac{T_s}{L_s}\widehat{e_\beta}[k-1] + \dfrac{T_s}{L_s}u_\beta[k-1] + h_1 T_s\left(-i_\beta[k-1]\right) \\ \widehat{e_\alpha}[k] = \widehat{e_\alpha}[k-1] + T_s\omega_e\widehat{e_\beta}[k-1] + h_2 T_s\left(\widehat{i_\alpha}[k-1] - i_\alpha[k-1]\right) \\ \widehat{e_\beta}[k] = \widehat{e_\beta}[k-1] - T_s\omega_e\widehat{e_\alpha}[k-1] + h_2 T_s\left(\widehat{i_\beta}[k-1] - i_\beta[k-1]\right) \end{cases}$$

去耦(设定ω_e=0) 简化观测器模型

$$\begin{cases} \widehat{i_\alpha}[k] = \left(1 - \frac{rT_s}{L_s} + h_1 T_s\right)\widehat{i_\alpha}[k-1] - \frac{T_s}{L_s}\widehat{e_\alpha}[k-1] + \frac{T_s}{L_s}u_\alpha[k-1] + h_1 T_s(-i_\alpha[k-1]) \\ \widehat{e_\alpha}[k] = \widehat{e_\alpha}[k-1] + h_2 T_s\left(\widehat{i_\alpha}[k-1] - i_\alpha[k-1]\right) \end{cases}$$

$$A_{reduced-obs} = \begin{bmatrix} 1 - \frac{rT_s}{L_s} + h_1 T_s & -\frac{T_s}{L_s} \\ h_2 T_s & 1 \end{bmatrix}$$

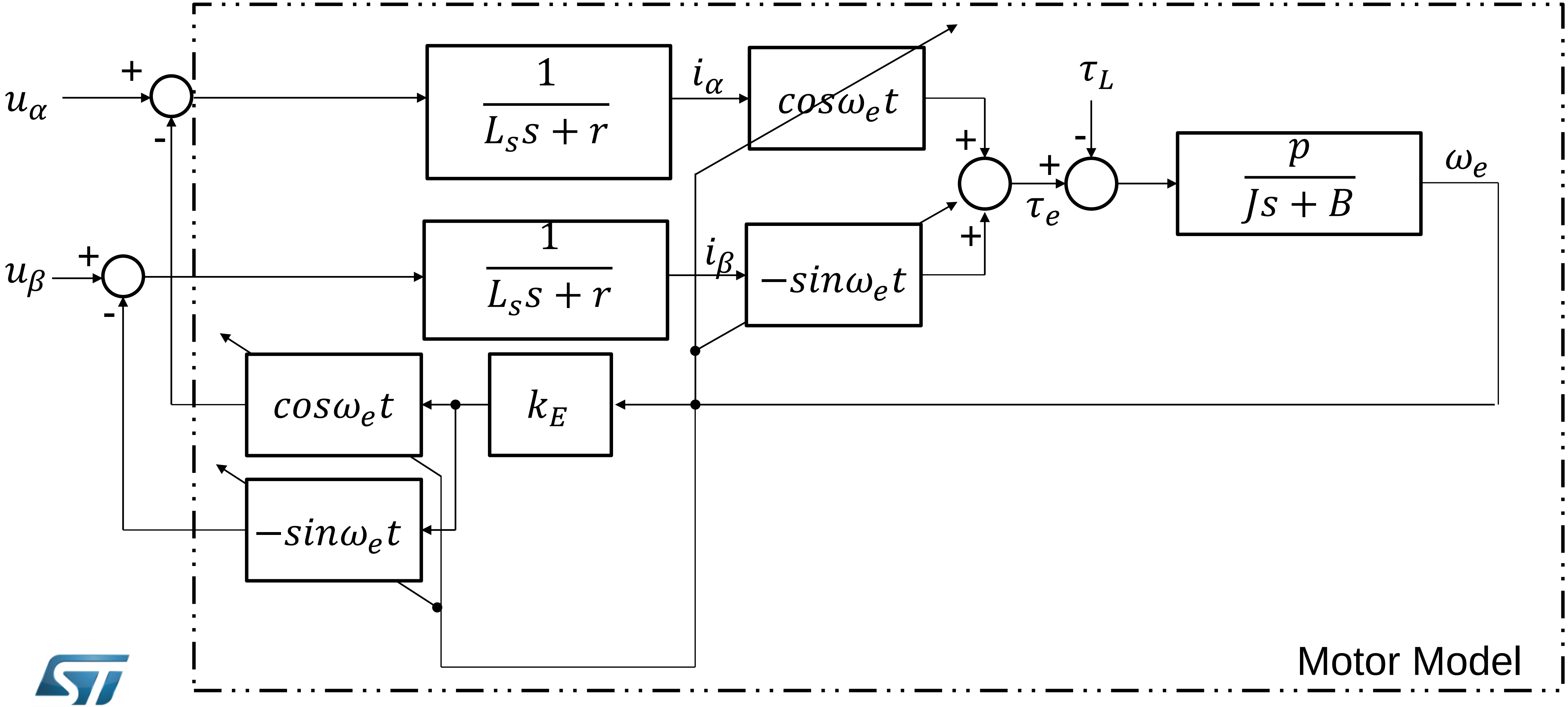
$$\begin{cases} \lambda_{1-obs} = \frac{\lambda_1}{k} \\ \lambda_{2-obs} = \frac{\lambda_2}{k} \end{cases} \quad k > 1$$

$$|\lambda I - A_{reduced-obs}| = (\lambda - \lambda_{1-obs})(\lambda - \lambda_{2-obs})$$

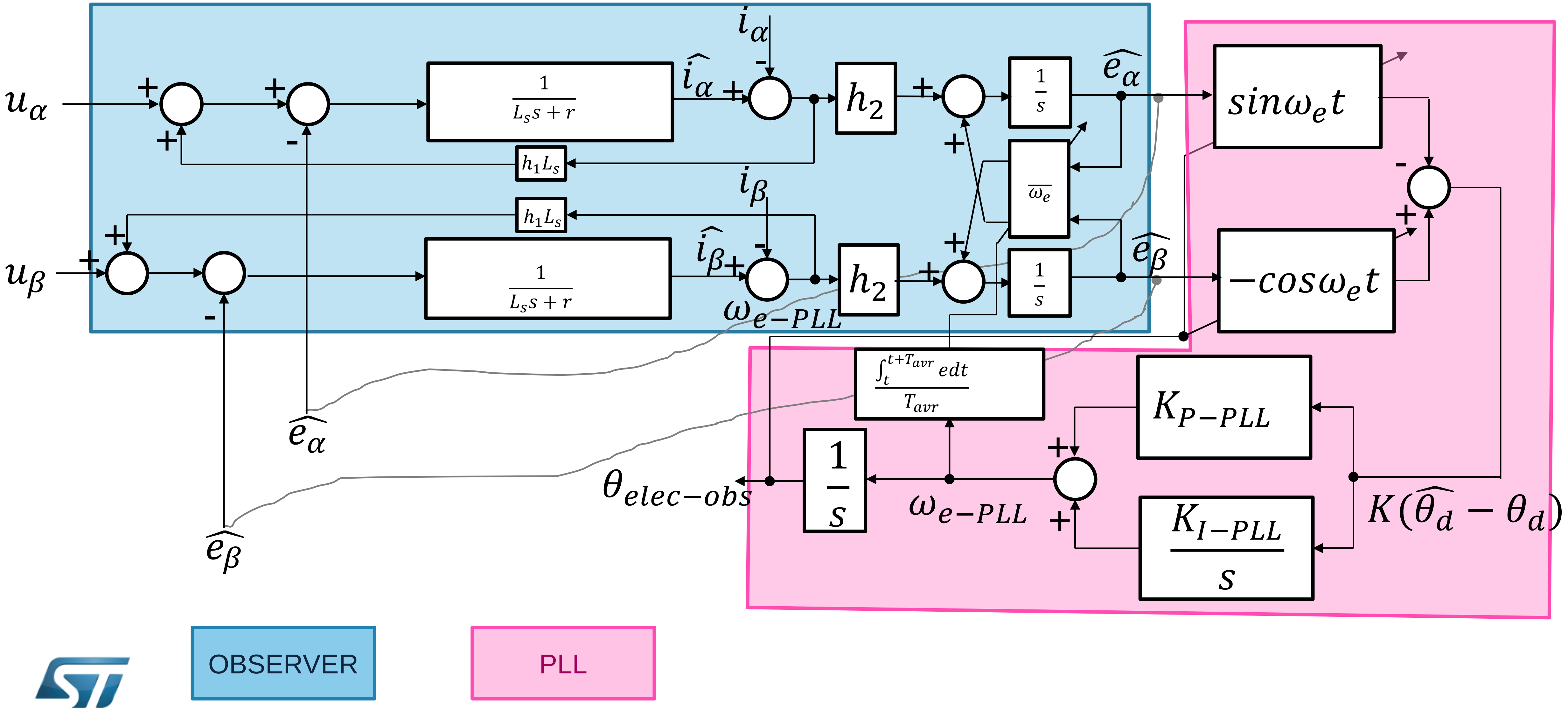
$$\begin{cases} h_1 = \frac{\lambda_{1-obs} + \lambda_{2-obs} - 2}{T_s} + \frac{r}{L_s} \\ h_2 = \frac{L_s(1 - \lambda_{1-obs} - \lambda_{2-obs} + \lambda_{1-obs}\lambda_{2-obs})}{{T_s}^2} \end{cases}$$

life.augmented

位置速度检测 — 观测器(9/11)

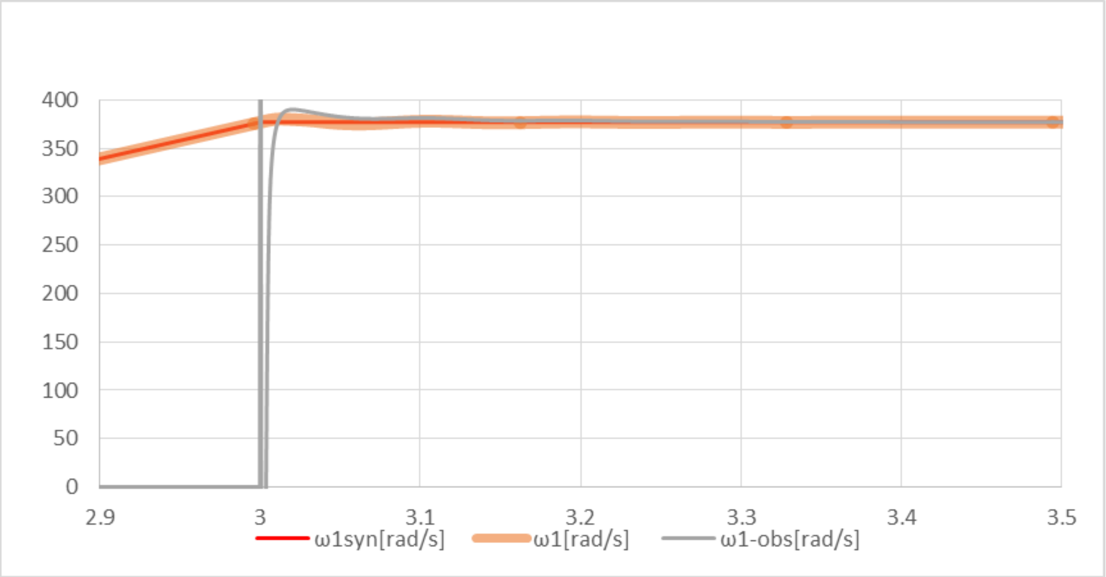


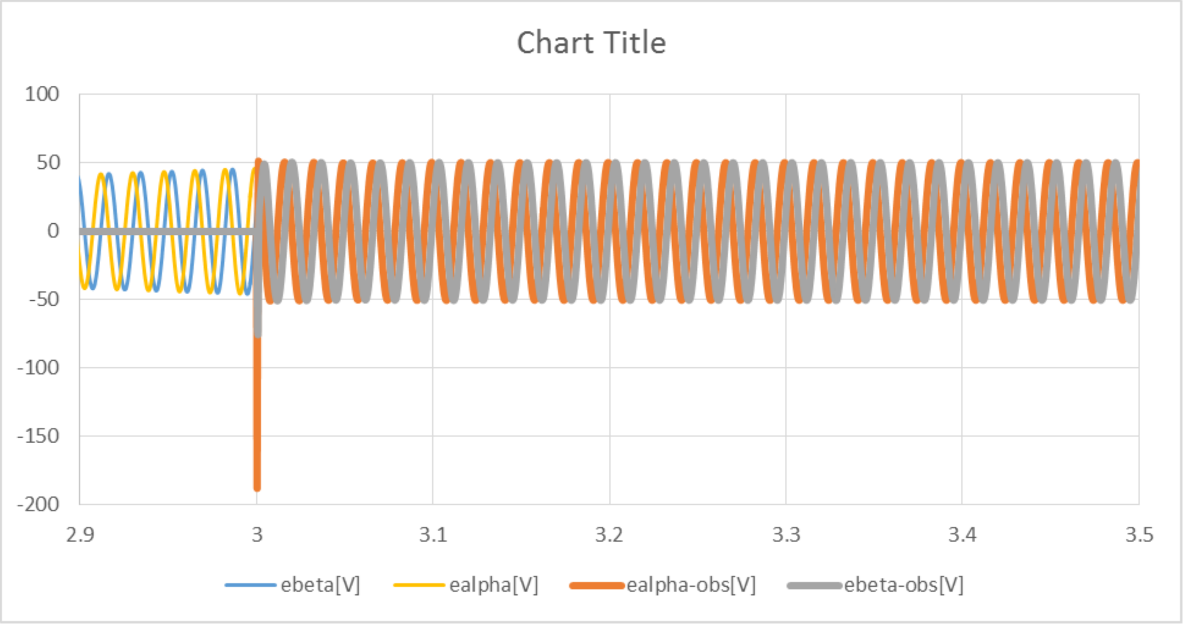
位置速度检测 — 观测器(10/11)

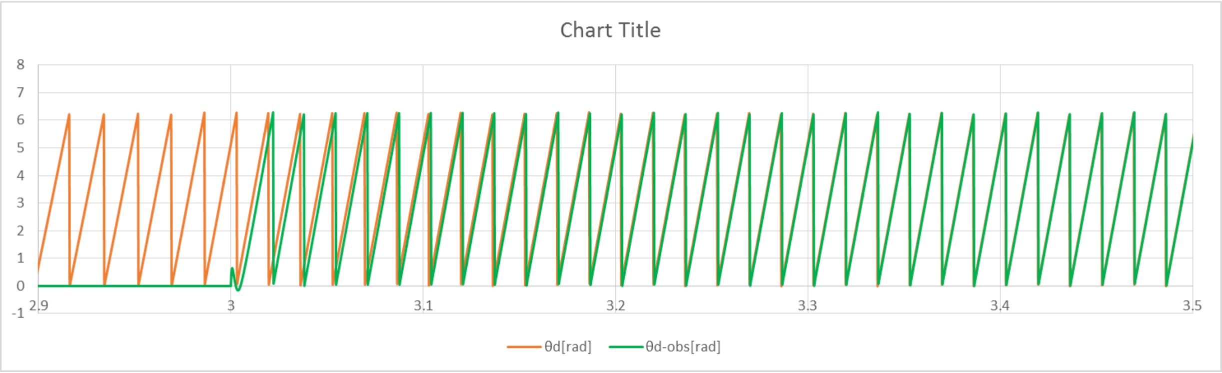


位置速度检测 — 观测器(11/11)

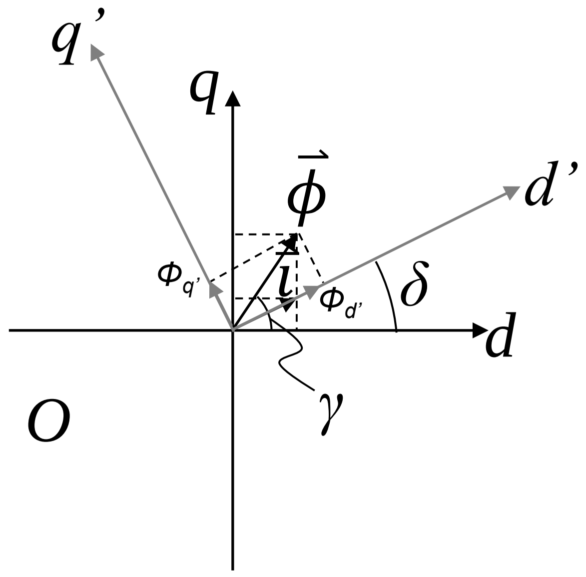
$$
\begin{cases}
\hat{i}_\alpha[k] = \left(1 - \dfrac{rT_s}{L_s} + h_1 T_s\right)\hat{i}_\alpha[k-1] - \dfrac{T_s}{L_s}\widehat{e_\alpha}[k-1] + \dfrac{T_s}{L_s}u_\alpha[k-1] + h_1 T_s i_\alpha[k-1] \\
\hat{i}_\beta[k] = \left(1 - \dfrac{rT_s}{L_s} + h_1 T_s\right)\hat{i}_\beta[k-1] - \dfrac{T_s}{L_s}\widehat{e_\beta}[k-1] + \dfrac{T_s}{L_s}u_\beta[k-1] + h_1 T_s i_\beta[k-1] \\
\qquad\qquad \widehat{e_\alpha}[k] = \widehat{e_\alpha}[k-1] + T_s\overline{\omega_1}\widehat{e_\beta}[k-1] + h_2 T_s\left(\hat{i}_\alpha[k-1] - i_\alpha[k-1]\right) \\
\qquad\qquad \widehat{e_\beta}[k] = \widehat{e_\beta}[k-1] - T_s\overline{\omega_1}\widehat{e_\alpha}[k-1] + h_2 T_s\left(\hat{i}_\beta[k-1] - i_\beta[k-1]\right)
\end{cases}
$$







位置速度检测 — HFI(1/4)



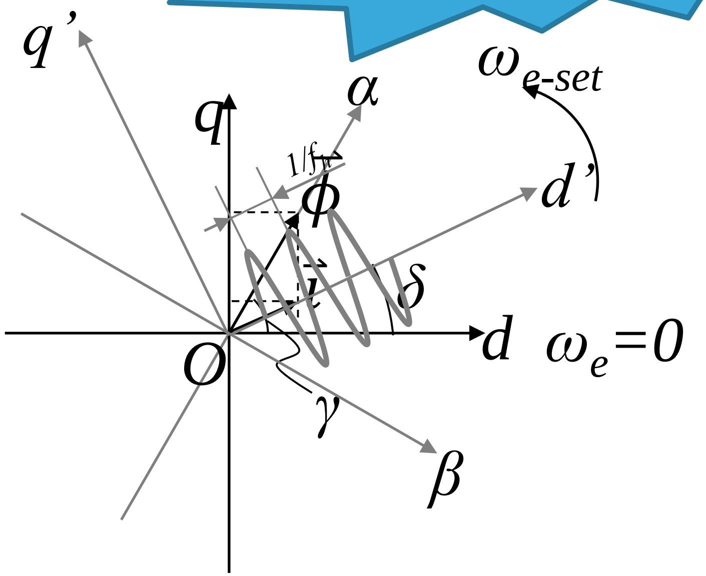
$$\tan\delta = \frac{I_q}{I_d}, \tan\gamma = \frac{L_q I_q}{L_d I_d} = \frac{L_q}{L_d}\tan\delta$$

$$\tan(\gamma-\delta) = \frac{\tan\gamma - \tan\delta}{1+\tan\gamma\tan\delta} = \frac{\left(\frac{L_q}{L_d}-1\right)\tan\delta}{1+\frac{L_q}{L_d}tan^2\delta} = \frac{(L_q-L_d)\sin 2\delta}{2\left[L_d+(L_q-L_d)sin^2\delta\right]}$$

$$|\vec{\phi}| = \sqrt{(L_d I_d)^2 + (L_q I_q)^2} = |\vec{i}|\sqrt{{L_d}^2 + ({L_q}^2 - {L_d}^2)sin^2\delta}$$

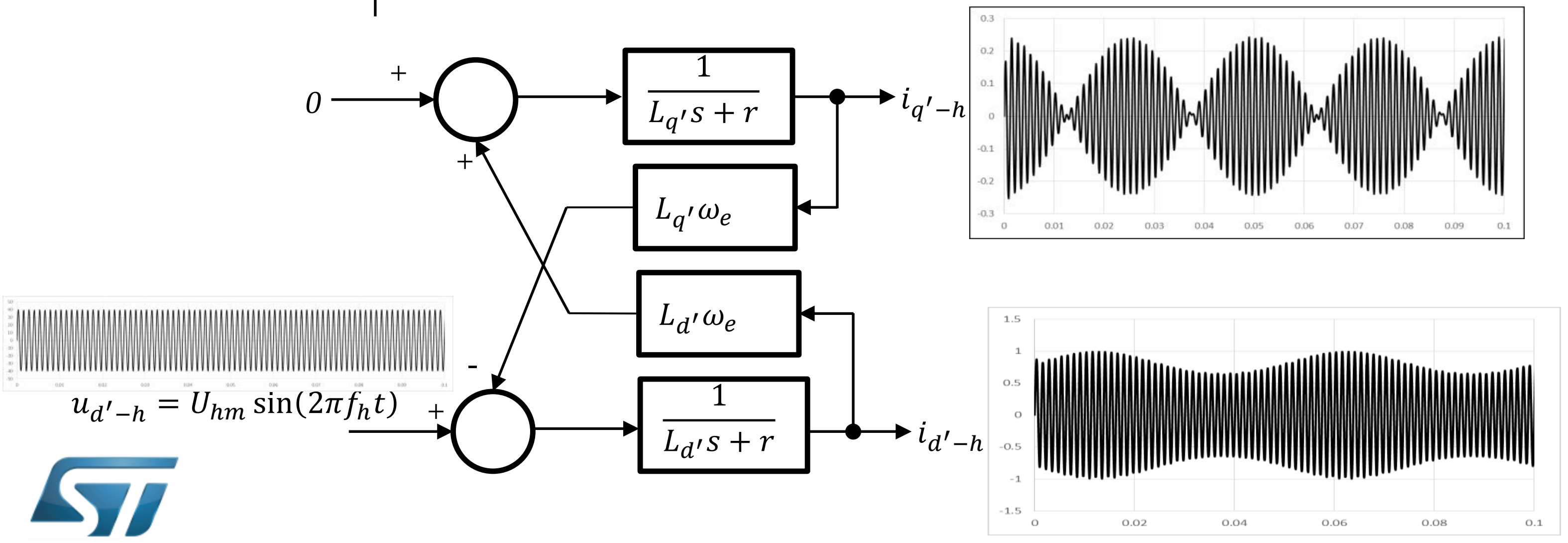
位置速度检测 — HFI(2/4)

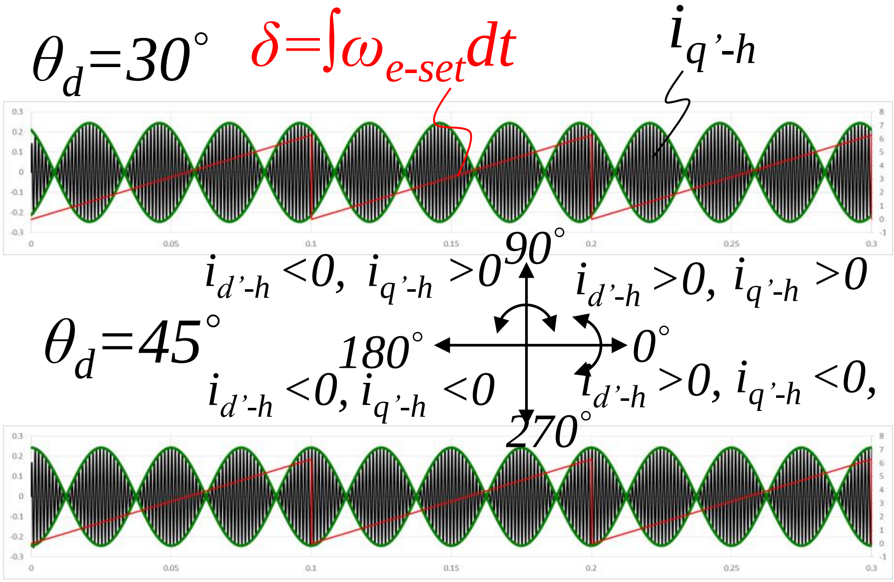
ST 专利
US932563 B1



$$|\vec{\phi}| = \sqrt{(L_d I_d)^2 + (L_q I_q)^2} = |\vec{i}|\sqrt{L_d{}^2 + (L_q{}^2 - L_d{}^2)sin^2\delta}$$

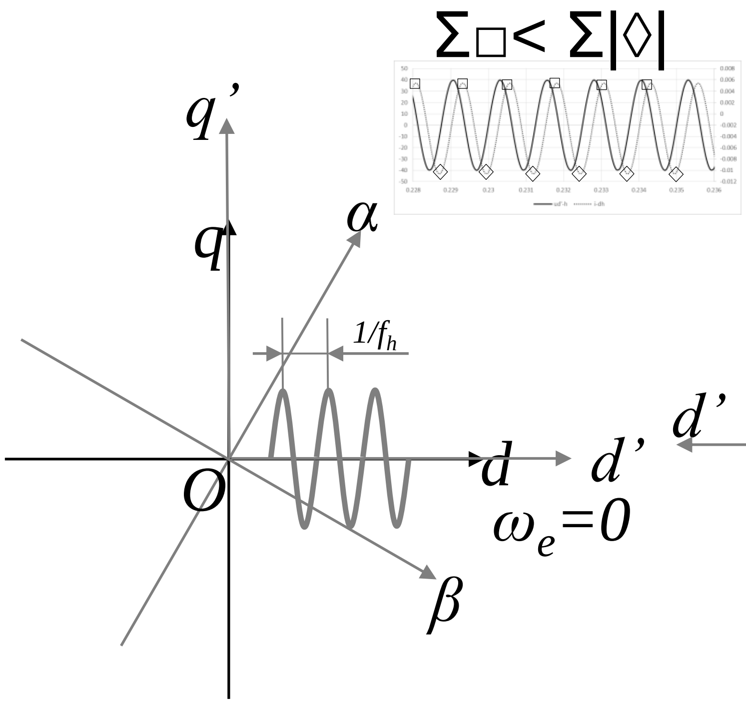
$$|\vec{\phi}| = I_m \sin(2\pi f_h t)\sqrt{L_d{}^2 + (L_q{}^2 - L_d{}^2)sin^2(\omega_e t + \delta_0)}$$

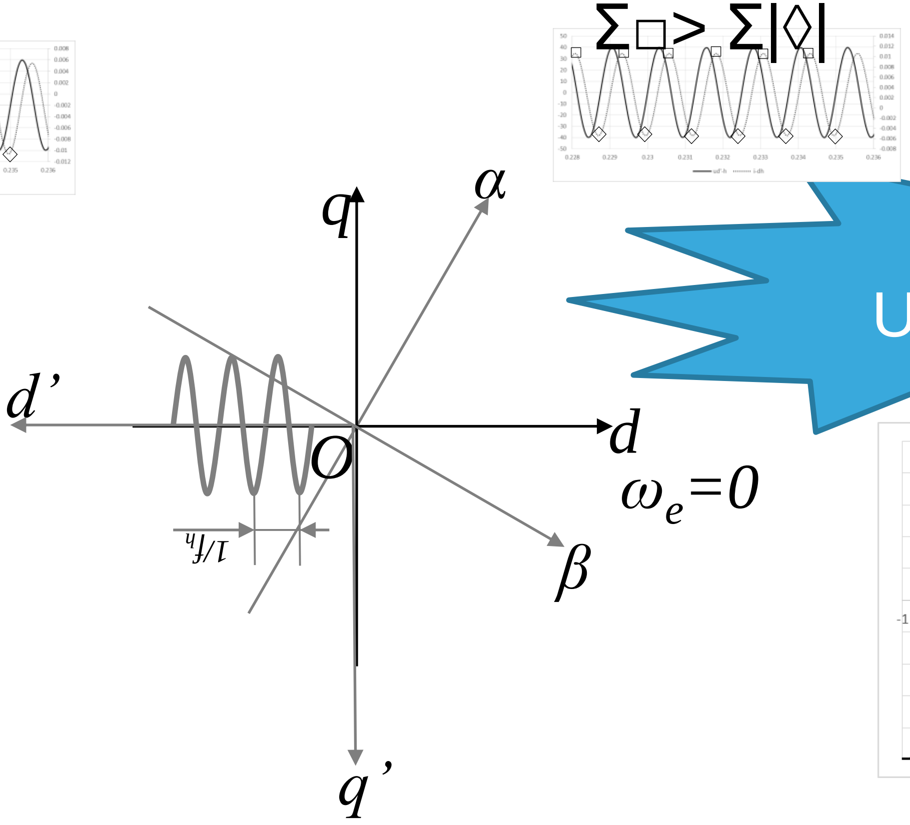




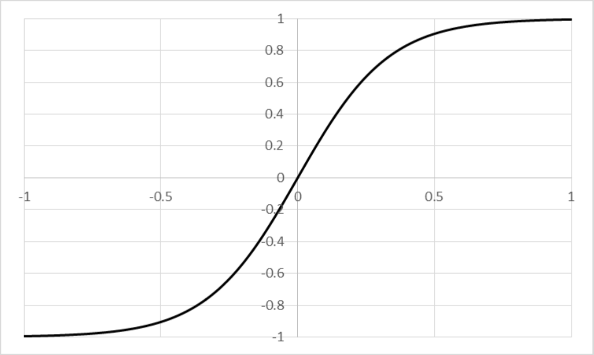
life.augmented

位置速度检测 — HFI(3/4)

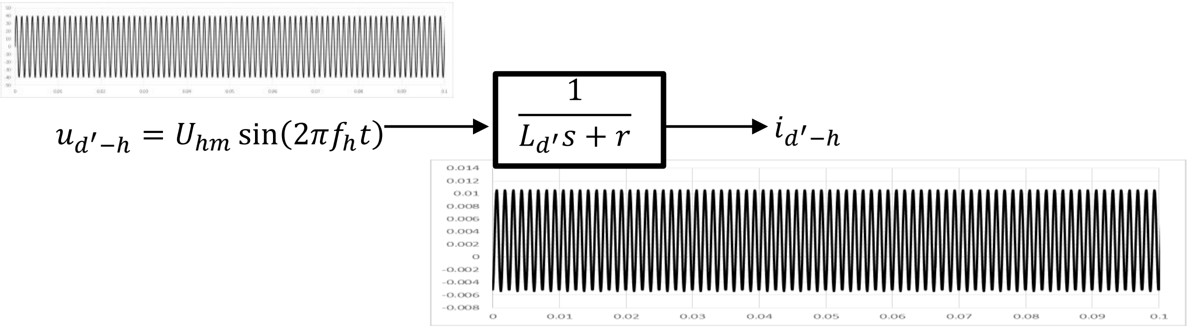




ST Patent
US932563 B1

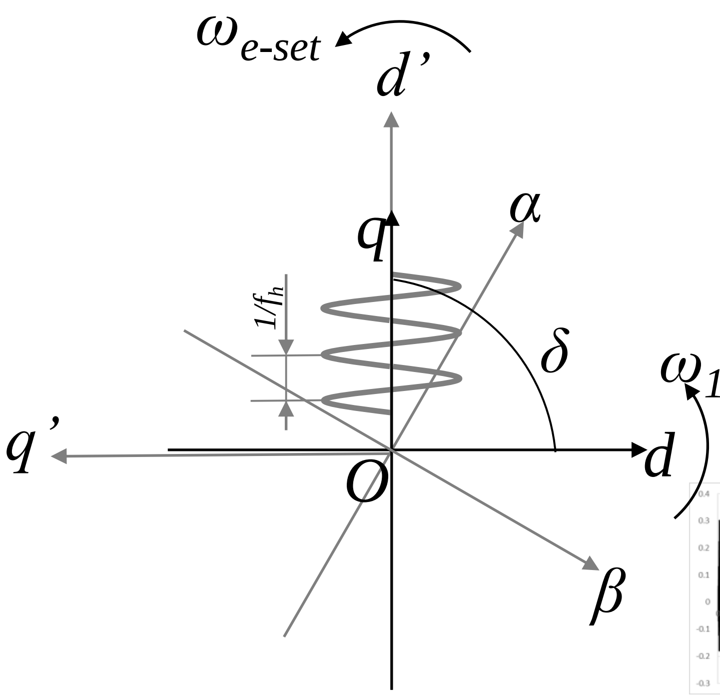


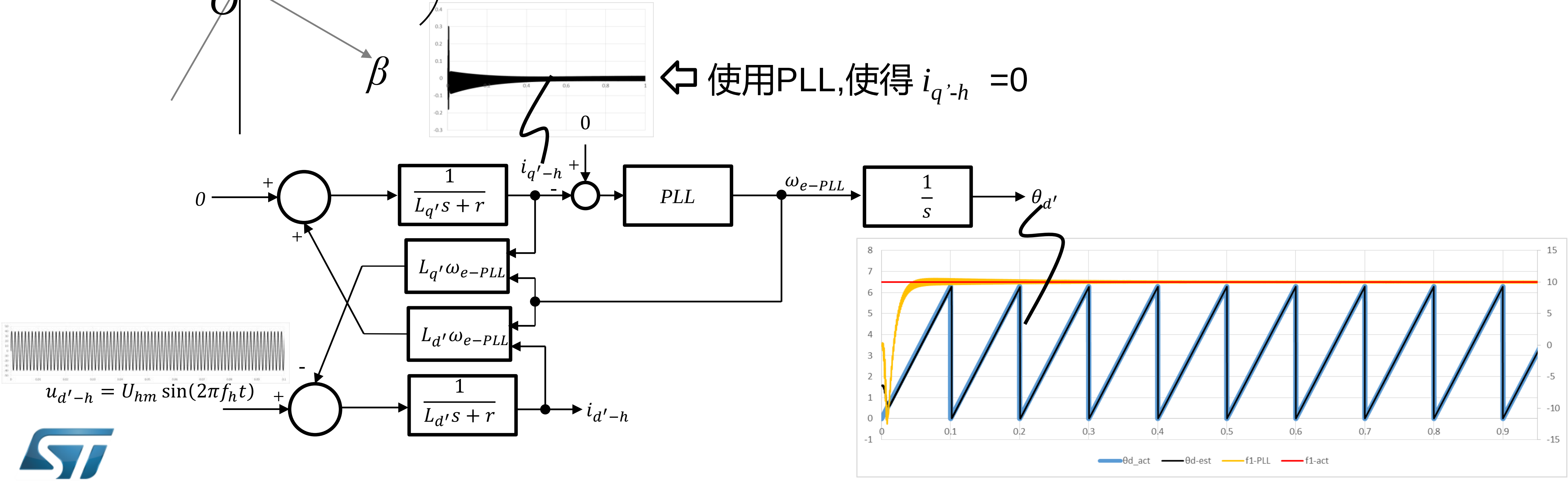
Φ-i 曲线



位置速度检测 — HFI(4/4)

当电机开始转动后，保持δ=0 ，d'轴与q轴重合，那么$i_{q'\text{-}h}$=0，
也就是如果保持$i_{q'\text{-}h}$=0， d'-q' 旋转坐标系的速度等于转子速度$\omega_e = \omega_{e\text{-}set}$.





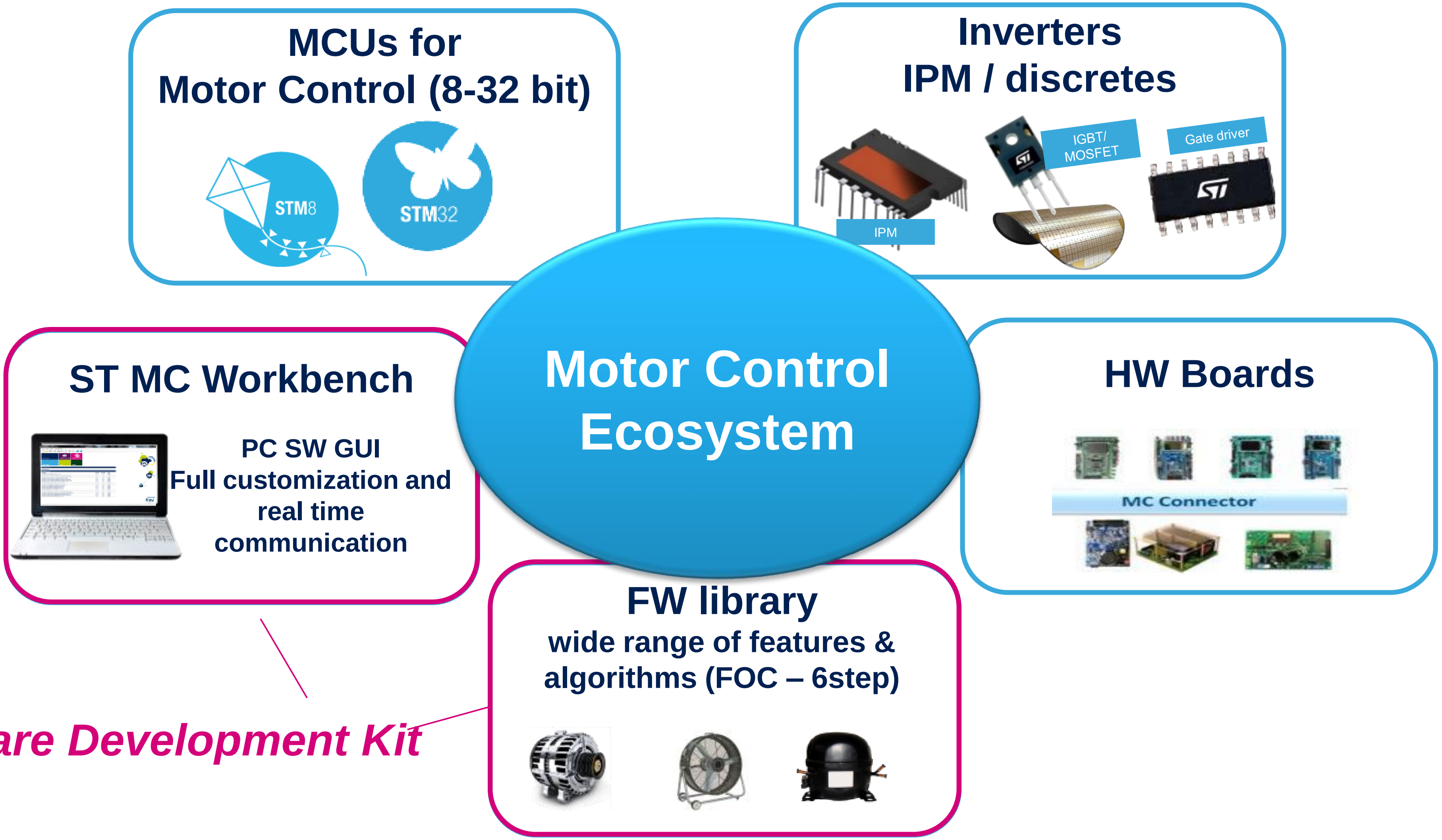
⇦ 使用PLL,使得 $i_{q'\text{-}h}$ =0

2.MC SDK5.0详解

内容

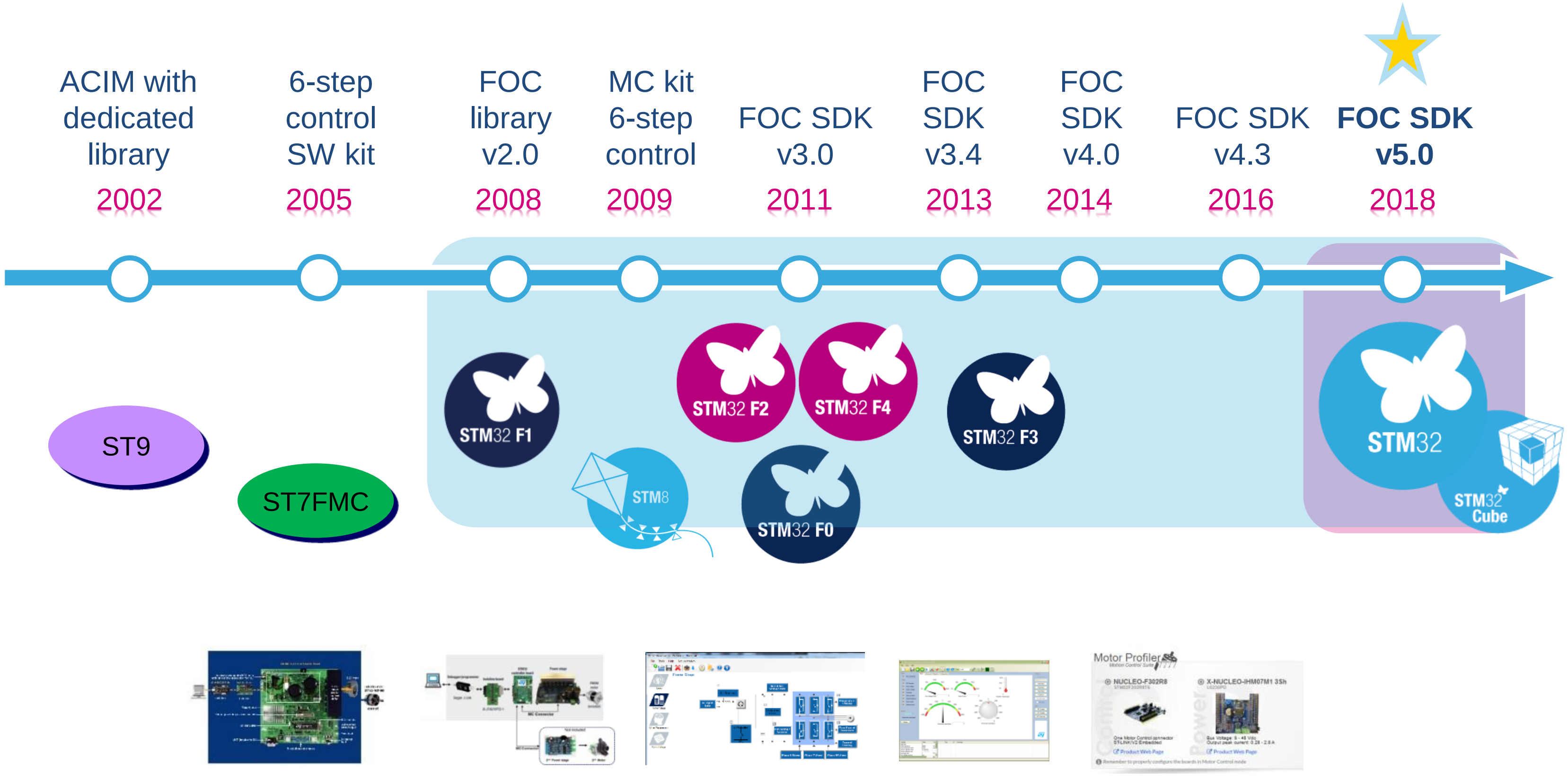
- ❑ STM32 电机控制开发套件 5.0 概览
- ❑ SDK 5.0 软件开发

STM32 电机控制开发套件 5.0 概览



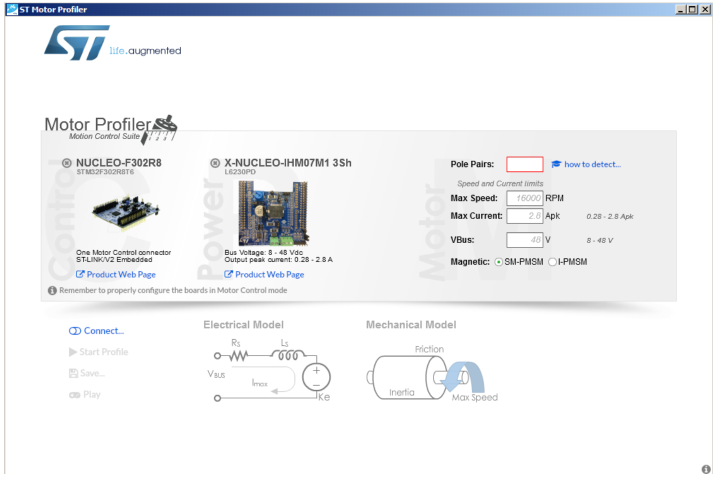
Software Development Kit (SDK)

STM32 电机控制开发套件 5.0 概览-历史

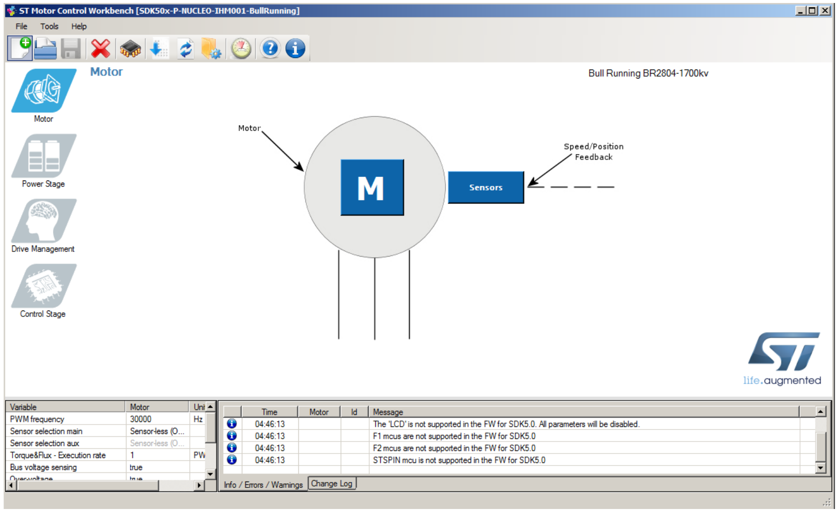


STM32 电机控制开发套件 5.0 概览-SDK 5.0 内容

软件工具



ST Motor Profiler tool



MotorControl Workbench

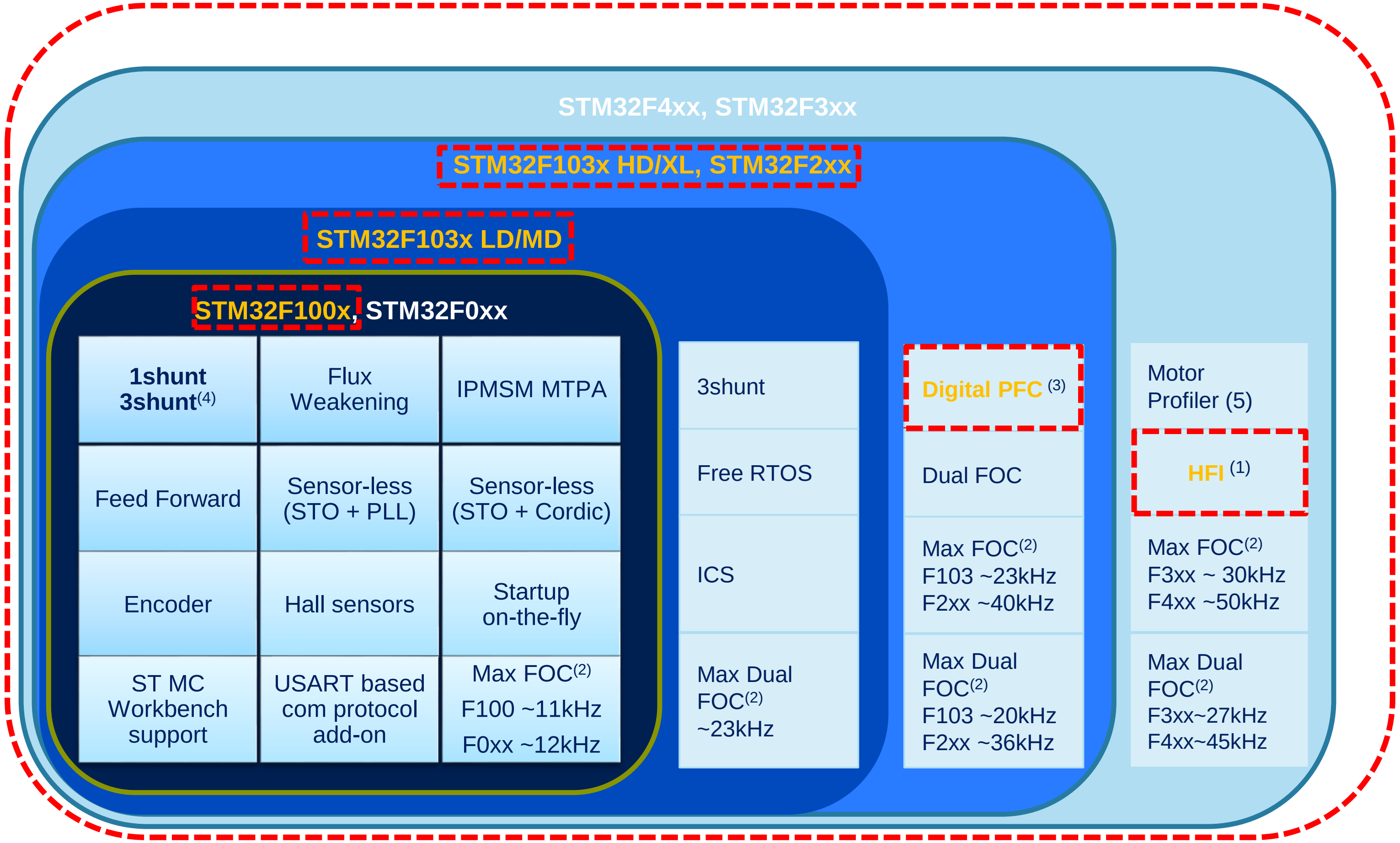
FOC 软件库

- _htmresc
- Documentation
- Middlewares
- Projects
- Utilities
- MCSDKUninstaller_5.0.3.exe
- Release Notes for X-Cube-MCSDK.html

- Applications
- Legacy
- lib
- MCSDK
- templates
- MotorControl_Configs.xml
- MotorControl_Modes.xml
- Release Notes for ST MC FOC FW.html

life.augmented

STM32 电机控制开发套件 5.0 概览-软件库功能



XXX Features and STM32 series to be added in next MC SDK release

(1)High Frequency Injection

(2)Max FOC estimated in sensorless mode

(3)STM32F103xC/D/E/F/G and STM32F303xB/C

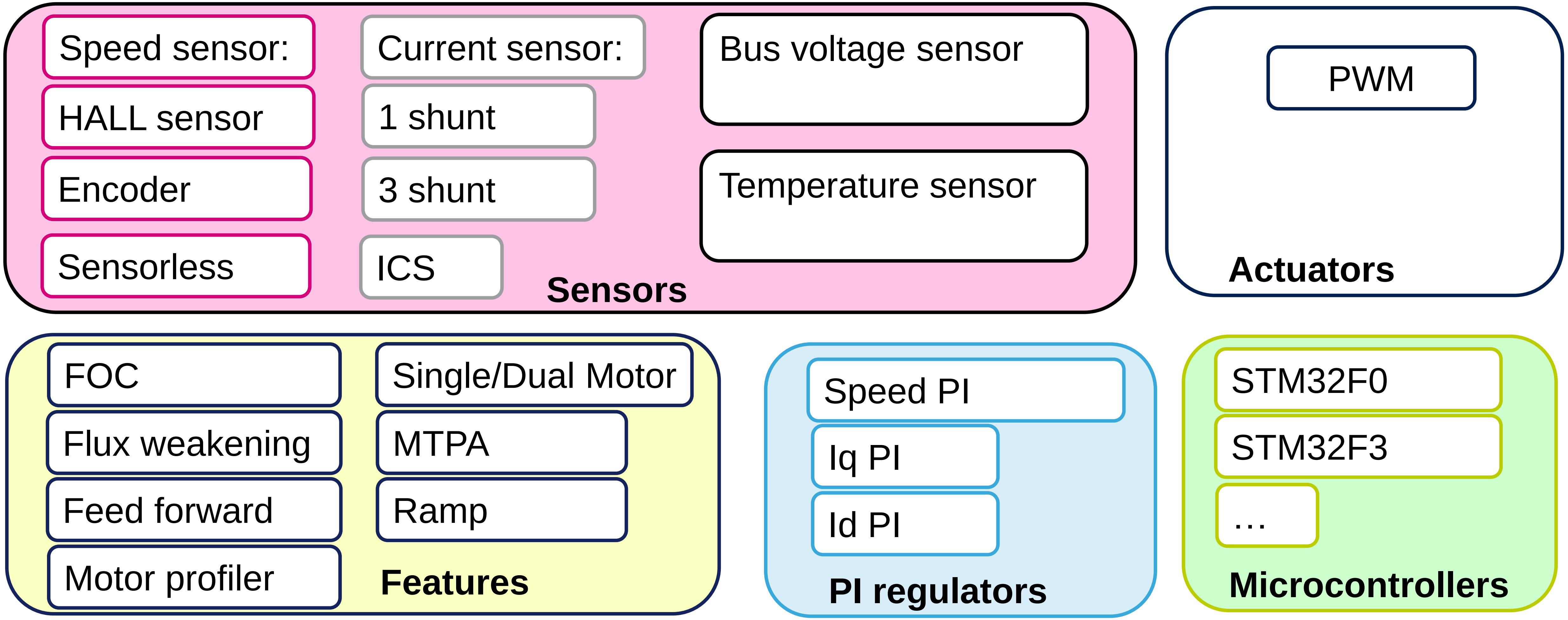
(4)Not for STM32F100

(5)For STM32F30x

life.augmented

STM32 电机控制开发套件 5.0 概览-软件库功能

功能模块

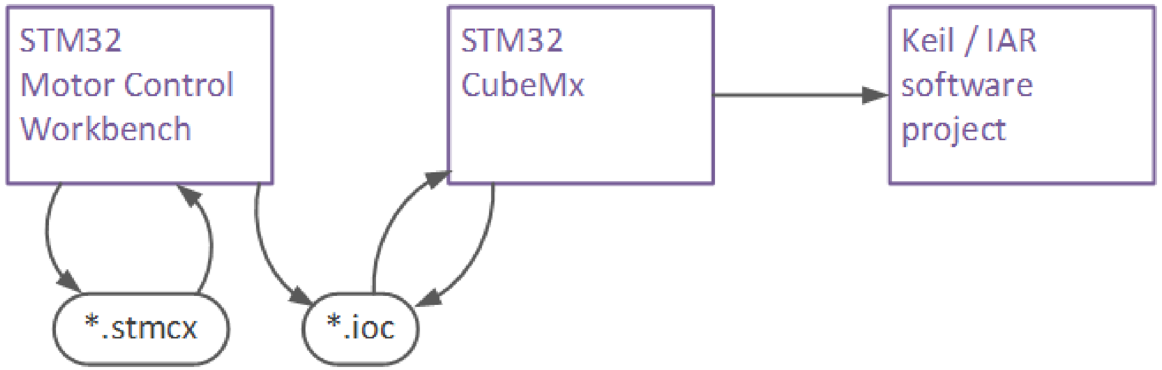


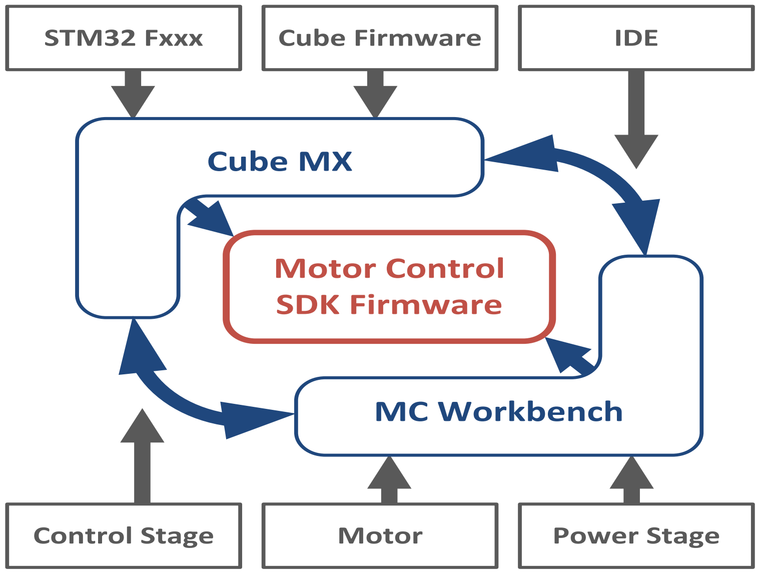
测试条件: PWM 频率20KHz / FOC 电流环控制频率

		MCSDK5.0					
MCU	Config	Workload (%).	Total Code size (kB).	ro data (B).	RAM (B).	FOC Lib (kB).	HAL (kB).
F072RB	1 Shunt	44.3	18.8	609	3126	12.8	5.1
F072RB	3 Shunt	39.4	19.5	653	2910	12.9	4.5
F303RE	1 Shunt	20.4	22.3	4427	2940	14.4	7.8
F303RE	3 Shunt	18.1	23.6	4179	2884	16.1	7.5
F446RE	1 Shunt	10.2	19.7	625	3122	14.4	5.3
F446RE	3 Shunt	8.2	17.8	603	2840	13.1	4.7
F303VE	DUAL/3S	38.2	20.8	4449	4724	13.1	7.7
F415ZG	DUAL/3S	18.3	19.3	761	4484	14.7	4.6

life.augmented

代码生成流程

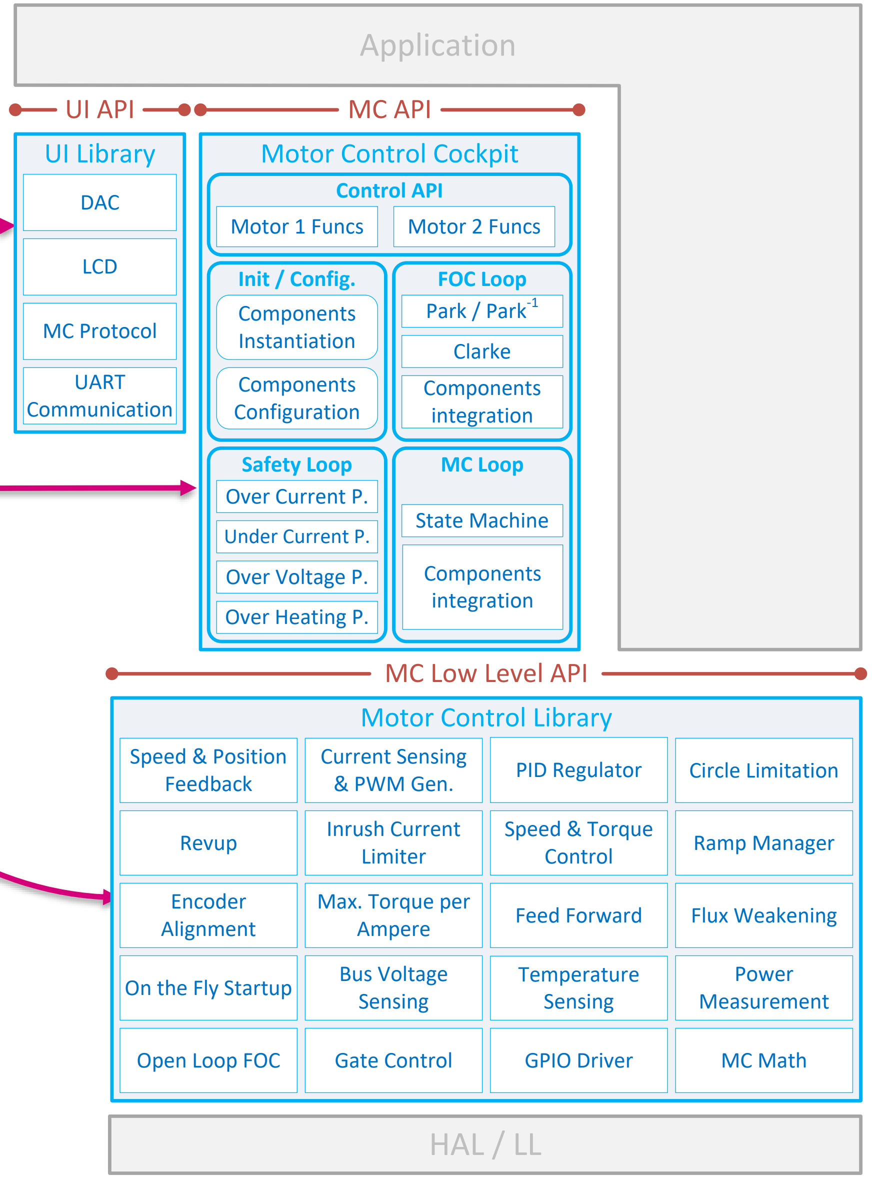

STM32
Motor Control
Workbench
STM32
CubeMx
Keil / IAR
software
project
*.stmcx
*.ioc


STM32 Fxxx
Cube Firmware
IDE
Cube MX
Motor Control
SDK Firmware
MC Workbench
Control Stage
Motor
Power Stage

STM32 电机控制开发套件 5.0 概览-软件库架构

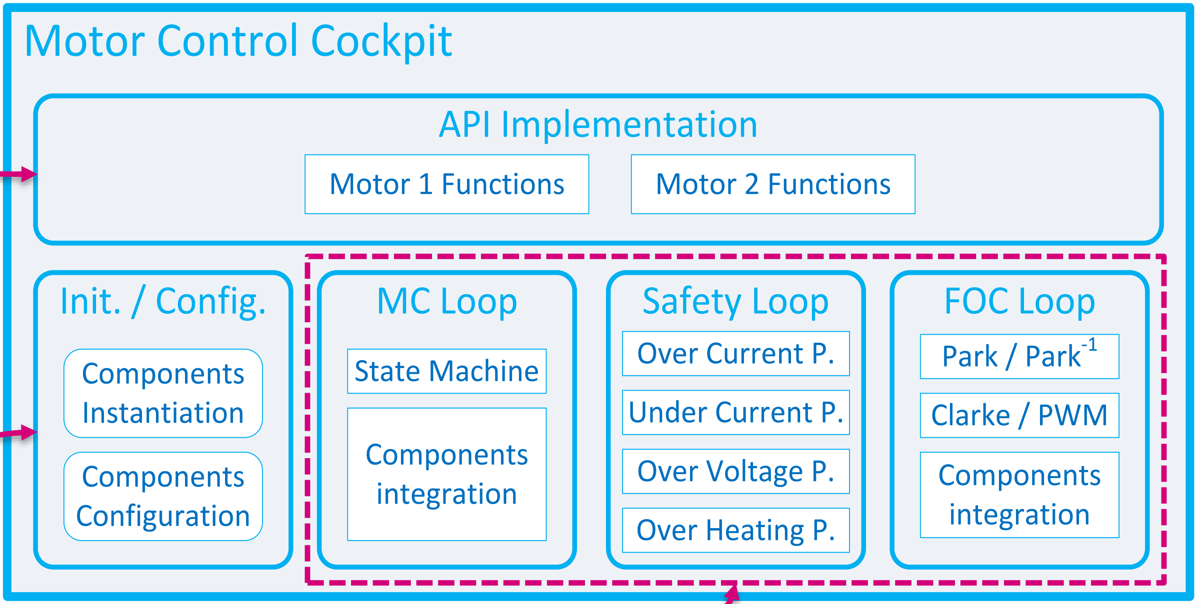
整个软件库由三部分组成

- 用户界面库
- 电机驾驶舱
- 电机控制库



STM32 电机控制开发套件 5.0 概览-软件库架构

电机驾驶舱



电机控制接口
通过 MC API来实现

电机控制配置
实例化并配置所有需要的组件。

电机控制动态
实现对电机动的动态控制：
- FOC控制环路(高频任务)
- 电机控制环路(中频任务)
- 安全控制环路 (安全任务)

STM32 电机控制开发套件 5.0 概览-软件库架构

电机控制库

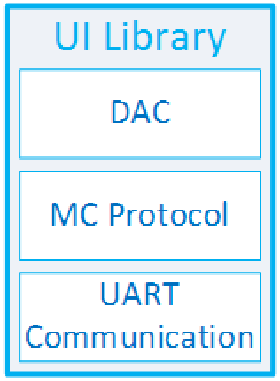
PMSM FOC Library

Speed & Position Feedback	Current Sensing & PWM Gen.	PID Regulator	Circle Limitation	Ramp Manager	Revup
Speed & Torque Control	Bus Voltage Sensing	Temperature Sensing	Inrush Current Limiter	Encoder Alignment	Open Loop FOC
Flux Weakening	Feed Forward	Max. Torque per Ampere	Power Measurement	GPIO Driver	On the Fly Startup

软件控制库

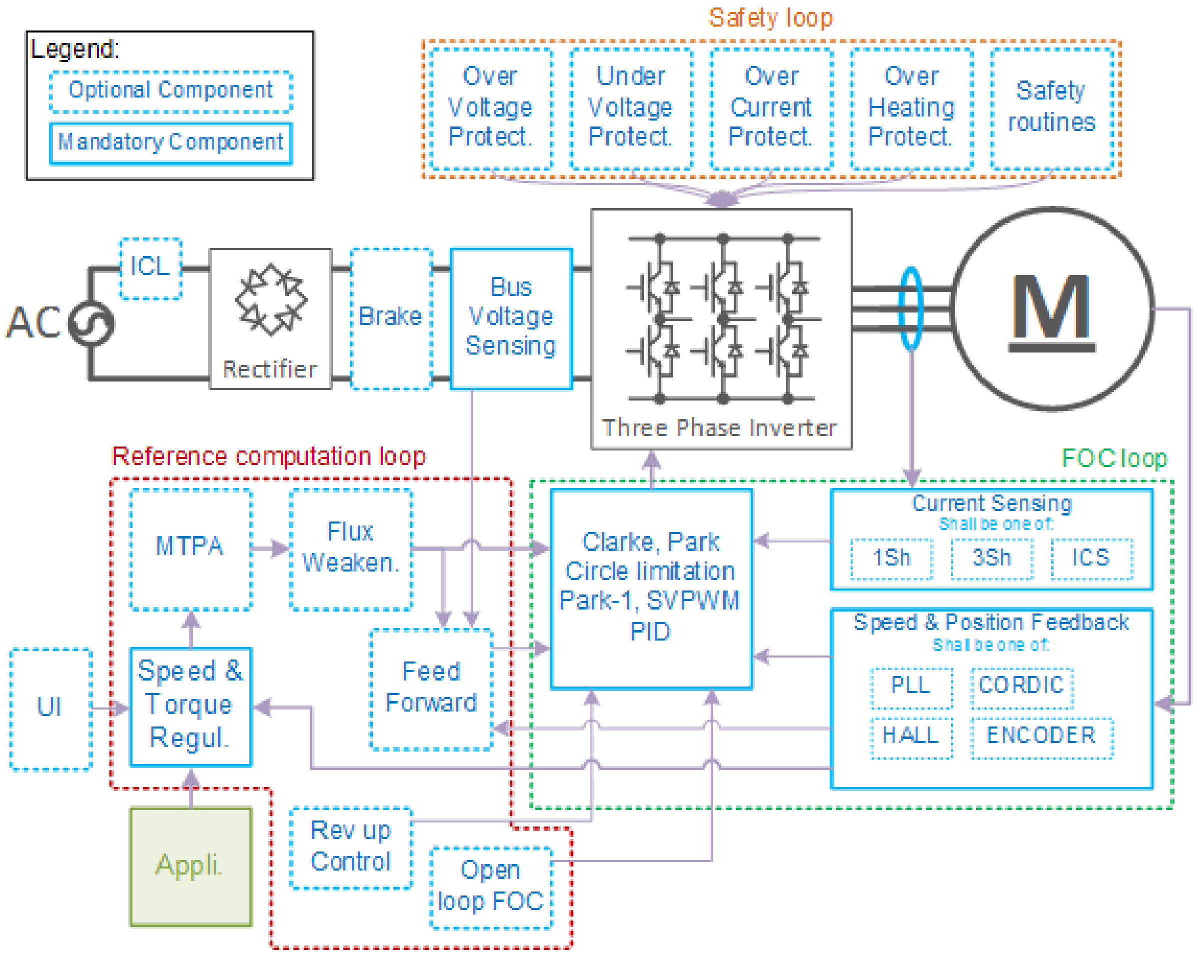
- 是诸多组件的集合。每一个组件实现电机控制的一个功能例如，速度和位置检测, 电流检测, PID算法等等…
- X-CUBE-MCSDK 中的组件不提供源代码，以库的形式提供。

用户界面库



用户界面库 包含负责通讯的组件。电机控制代码通过这些组件控制串口和DAC与外界通讯。通过这个库我们可以连接MCU和Workbench。在Workbench中实现对电机运行状态的监控。

STM32 电机控制开发套件 5.0 概览-软件库架构



程序由 Workbench 自动生成

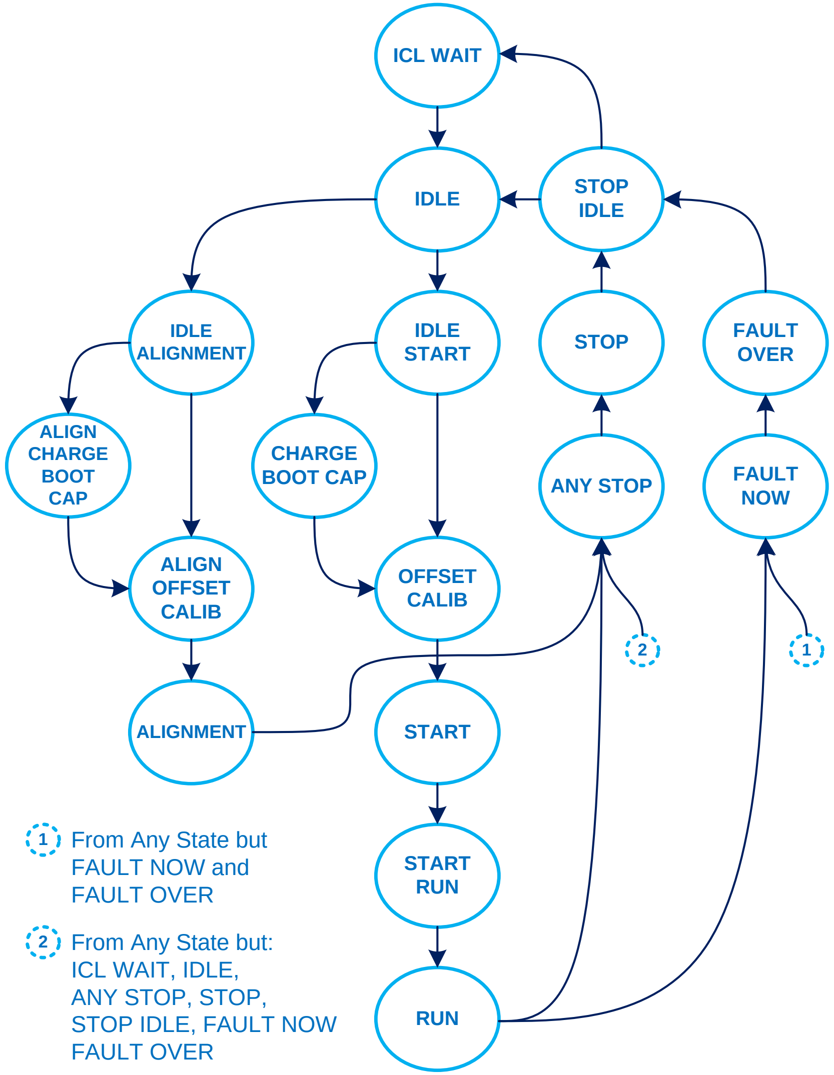
基于用户在Workbench工程中的配置。

自动生成程序的优点

简短: 只生成真正需要的组件。

简单: 程序中没有(#ifdef / #else / #endif)等条件编译。

高效: 没有虚函数. 直接调用函数实现。



电机控制状态机

- 程序中每一个电机都有一个独立运行的状态机来控制电机状态。
- 用户不可以直接操作状态机，而应该通过 SDK 提供的 API 来改变电机状态。

STM32 电机控制开发套件 5.0 概览-从 SDK 4.3 到 SDK5.0 的改进

改进点 (相对与4.3)	改进的理念
简化程序结构(不再面向对象) (固件) • 不再面向对象编程 • 不再数据隐藏 • 删除虚拟函数	• 易于调试 • 易于扩展开发
基于STM32Cube (固件) • 用HAL/LL代替原来的SPL	• 与STM32 固件开发策略保持一致 • 与STM32新产品无缝对接。现在支持的系列包括F0,F2,F4,F3等，还会加入L4,F7,H7等新产品，及后续上市的更新的产品。STM32产品线全线覆盖
建立了CUBEMX 与 WORKBENTCH 之间的联系(工具) • Cube MX => 应用CUBEMX初始化全部所需要的MCU外围模块。	• 与STM32开发工具策略保持一致 • 应用CUBE MX对MCU的外围设备做初始化 • 简化用户开发流程

life.augmented

STM32 电机控制开发套件 5.0 概览-从 SDK 4.3 到 SDK5.0 的改进

简化程序结构

SDK 4.3

PWMnCurrFdbkClass.c

```c
*           of phase A and B in Curr_Components format.
* @retval none.
*/
void PWMC_GetPhaseCurrents(CPWMC this,Curr_Components* pStator_Currents)
{
  int16_t hIa, hIb;
  pVars_t pVars = CLASS_VARS;
  (CLASS_METHODS.pPWMC_GetPhaseCurrents)(this, pStator_Currents);
  hIa = pStator_Currents->qI_Component1;
  hIb = pStator_Currents->qI_Component2;
  pVars->hIa = hIa;
  pVars->hIb = hIb;
  pVars->hIc = -hIa - hIb;
}
```

SDK 5.0

pwm_curr_fdbk.c

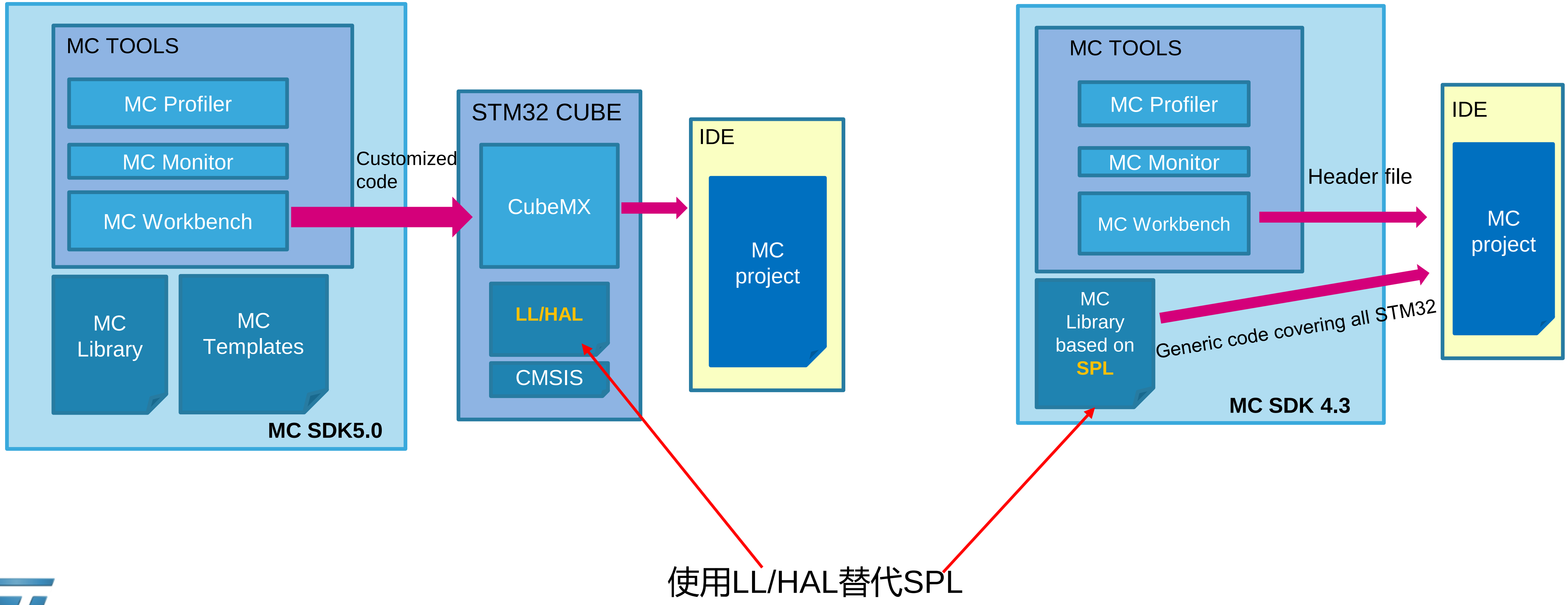
PWMC_GetPhaseCurrents(PWMC_Handle_t *, Curr_Components *)

```c
  * @retval none.
*/
void PWMC_GetPhaseCurrents(PWMC_Handle_t *pHandle,Curr_Components* pStator_Currents)
{
  pHandle->pFctGetPhaseCurrents(pHandle, pStator_Currents);
}
```

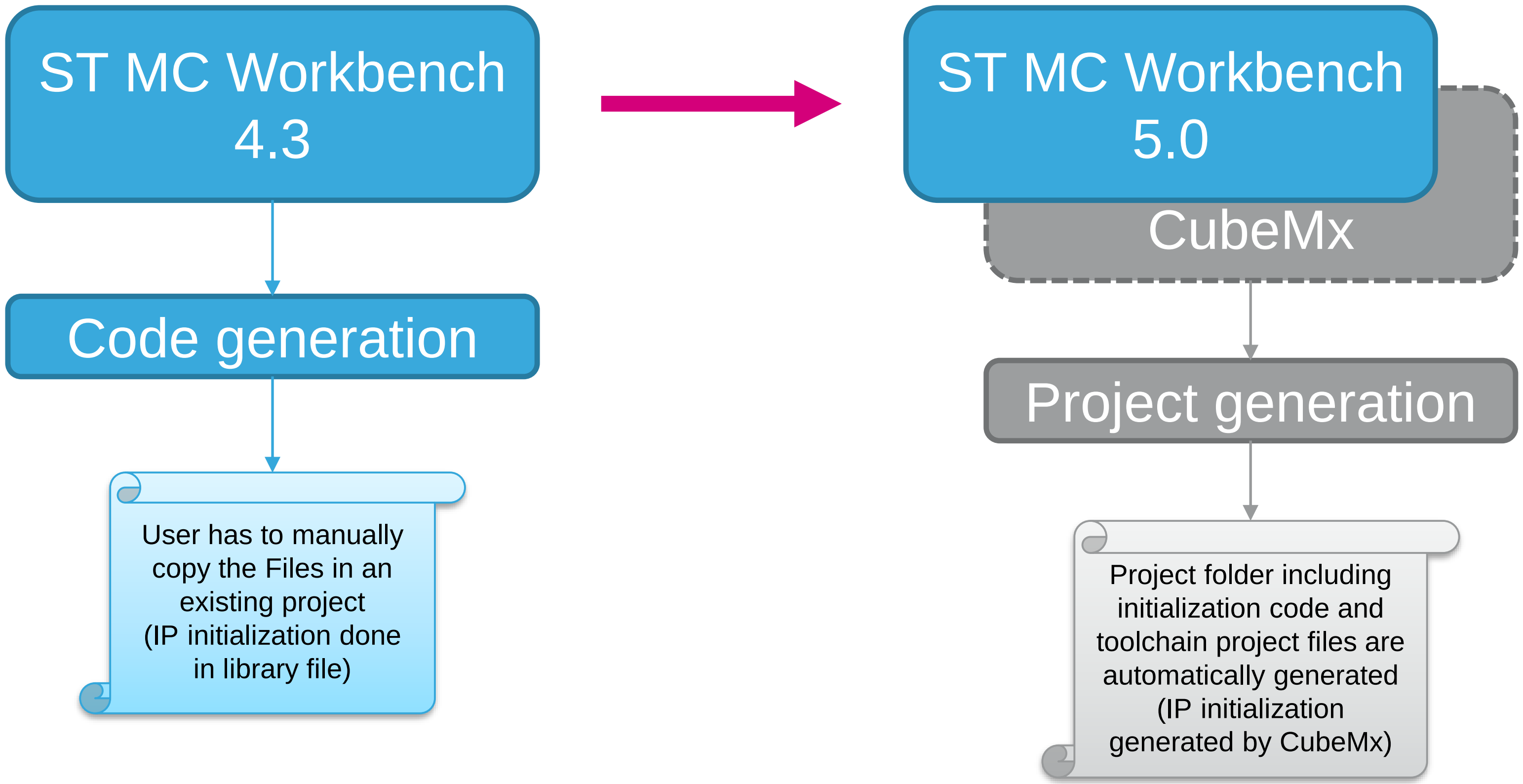
不再面向对象编程
- 用组件替代类
- 用函数替代方法

不再数据隐藏
- 组件所有的全局变量都定义在 PWMC_Handle_t 里，这个结构体可以在文件 pwm_curr_fdbk.h 中找到. 在 SDK 4.3 中class 的部分数据成员隐藏在文件 PWMnCurrFdbkPrivate.h, 中调用时只在class内部才转换成能看到的数据结构.

STM32 电机控制开发套件 5.0 概览-从 SDK 4.3 到 SDK5.0 的改进

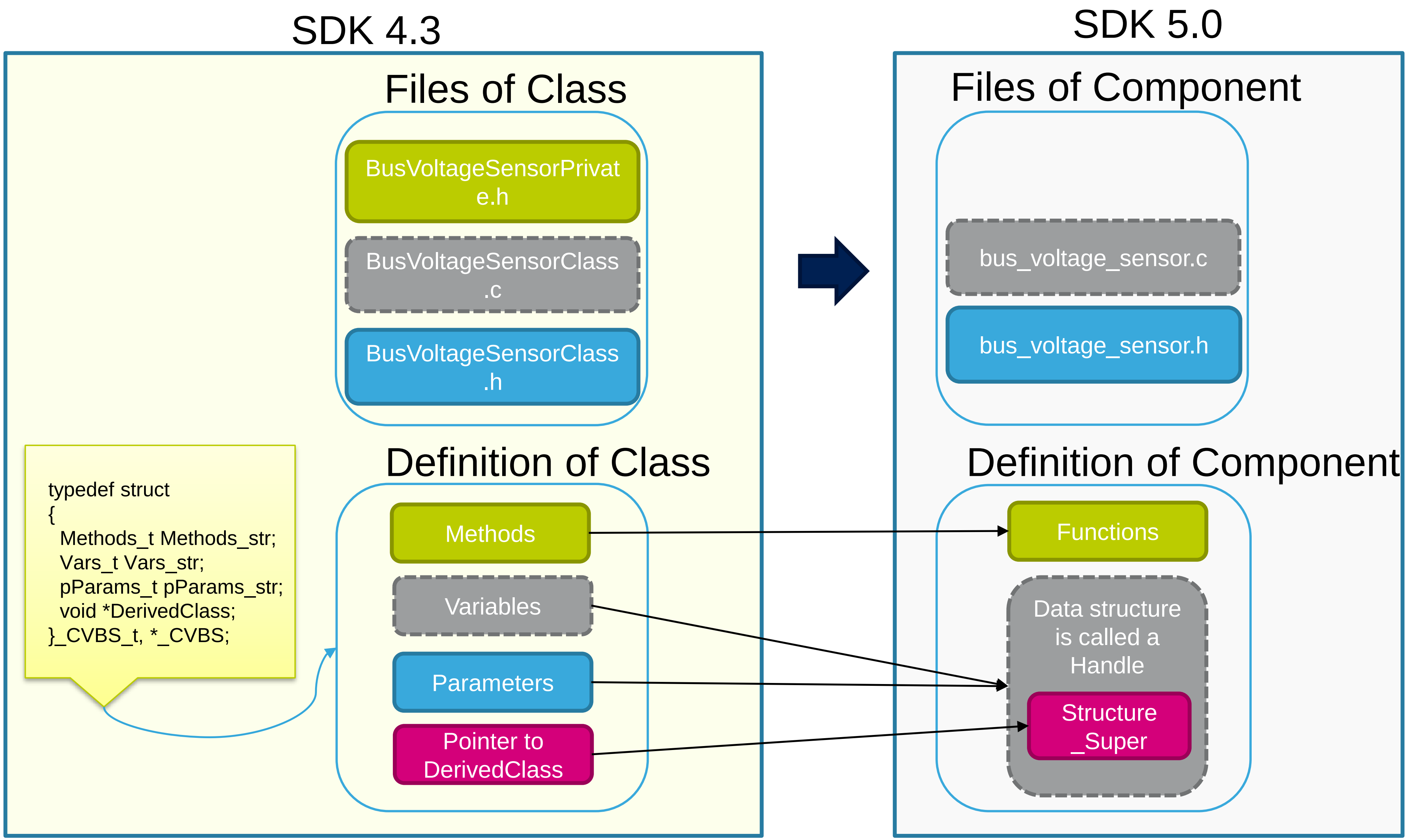


STM32 电机控制开发套件 5.0 概览-从 SDK 4.3 到 SDK5.0 的改进



Cube MX 初始化外设
Workbench 调用 CubeMx 生成整个程序，程序中包含了所有必要的源文件和头文件。但 CubeMx 运行在后台，无需客户操作。从使用者角度，表面上所有的生成程序的工作都是在 Workbench 完成的。

STM32 电机控制开发套件 5.0 概览-组件和类的对比



STM32 电机控制开发套件 5.0 概览-组件和类的对比

SDK 4.3 .h file

公开的类定义，只声明一个 void 型的指针用来隐藏实际的数据类型

```
typedef struct CVBS_t *CVBS;
```

Removed

参数结构体类型, 包含了所有需要的常量的结构体。

```
typedef const struct
{
  SensorType_t  bSensorType;
  uint16_t hConversionFactor;
}BusVoltageSensorParams_t,
*pBusVoltageSensorParams_t;
```

类的方法,对象的内部状态的操作必须通过这些方法来实现。

```
uint16_t VBS_GetBusVoltage_d(CVBS this);

uint16_t VBS_GetAvBusVoltage_d(CVBS this);
```

对象的变量结构体的定义。

```
typedef struct
{
  uint16_t hLatestConv;
  uint16_t hAvBusVoltage_d;
  uint16_t hFaultState;
}Vars_t,*pVars_t;
```

虚方法指针

```
typedef struct
{
  void (*pVBS_Init)(CVBS this,CPWMC oPWMnCurrentSensor);
  void (*pVBS_Clear)(CVBS this);
  uint16_t (*pVBS_CalcAvVbus)(CVBS this);
}Methods_t,*pMethods_t;
```

实际的类定义, 包含一个指向这个类的指针。

```
typedef struct
{
  Methods_t Methods_str;
  Vars_t Vars_str;
  pParams_t pParams_str;
  void *DerivedClass;
}_CVBS_t, *_CVBS;
```

Removed

SDK 5.0 .h 文件

```
uint16_t VBS_GetBusVoltage_d(
BusVoltageSensor_Handle_t *pHandle);

uint16_t VBS_GetAvBusVoltage_V(
BusVoltageSensor_Handle_t *pHandle);
```

```
typedef struct
{
  SensorType_t SensorType;
  uint16_t ConversionFactor;
  uint16_t LatestConv;
  uint16_t AvBusVoltage_d;
  uint16_t FaultState;
}BusVoltageSensor_Handle_t;
```

life.augmented

SDK 4.3 .c file

```
#define BCLASS_VARS   ((_CVBS)this)->Vars_str

uint16_t VBS_GetAvBusVoltage_d(CVBS this)
 {
   return(BCLASS_VARS.hAvBusVoltage_d);
 }
```

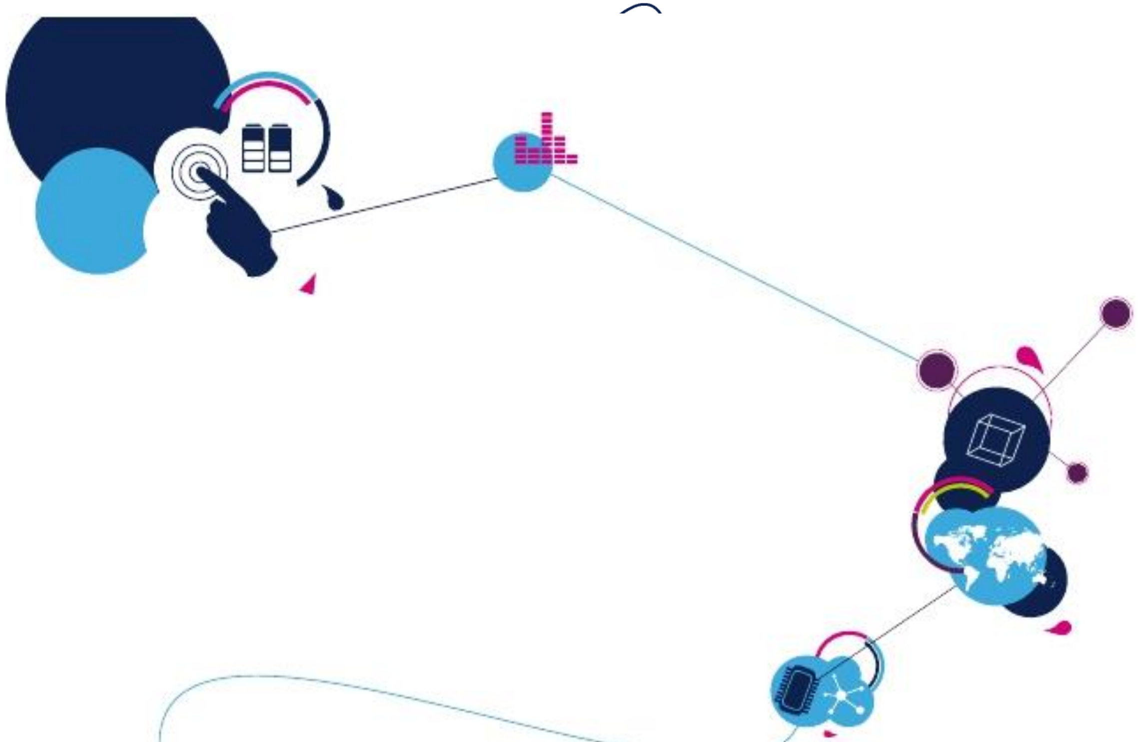
操作变量需要先将void*的指针转换成实际数据类型的指针，效率低.

SDK 5.0 .c file

```
uint16_t VBS_GetAvBusVoltage_d(BusVoltageSensor_Handle_t *pHandle)
 {
   return(pHandle->AvBusVoltage_d);
 }
```

没有数据隐藏直接操作变量所在的结构体。

life.augmented



SDK 5.0 软件开发

- **IDE 是 IAR Embedded Workbench 8**

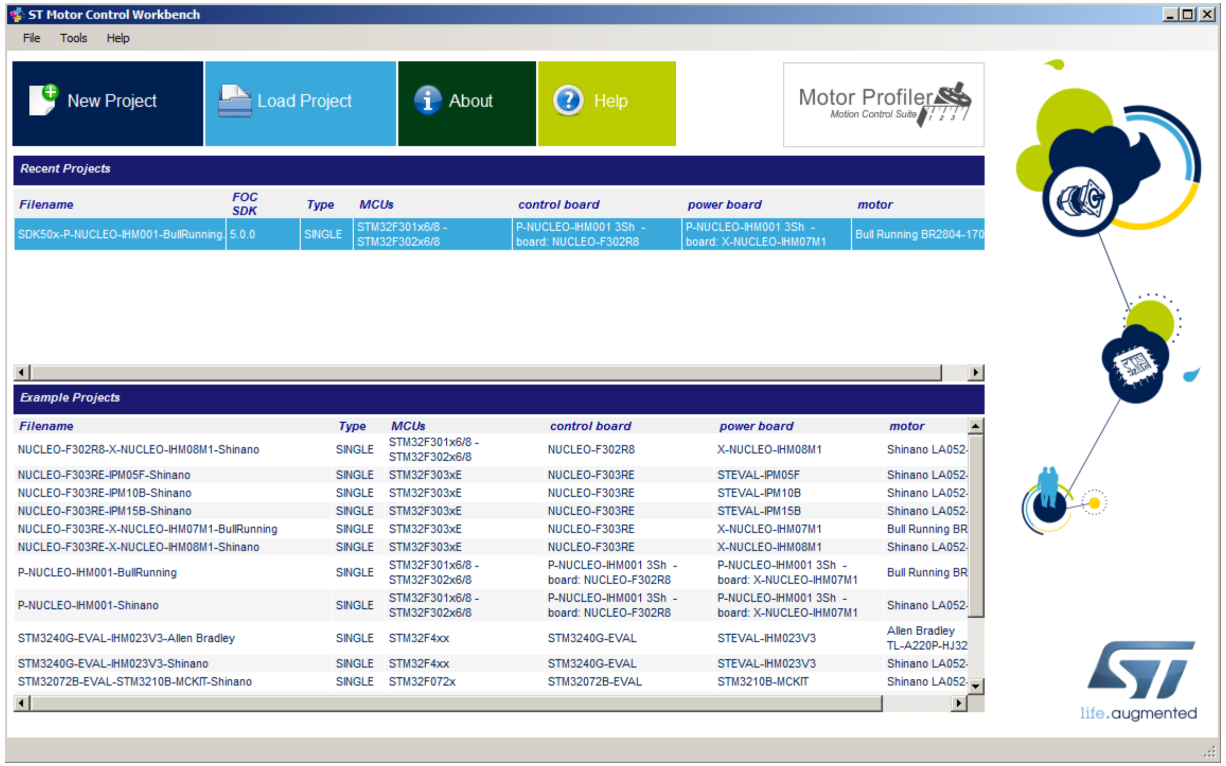
- **开发板选用 P-NUCLEO-IHM001 或者 P-NUCLEO-IHM002**

低成本电机开发套件

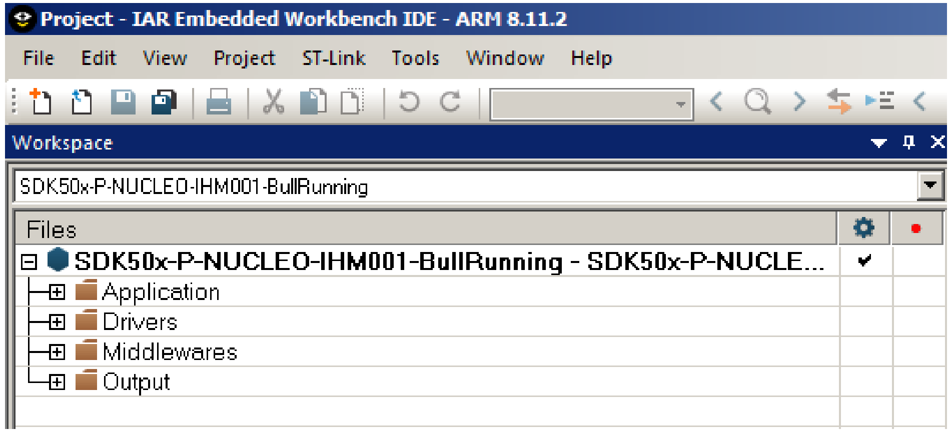
此开发套件被设计用于评估 BLDC 电机控制(最高电压 36V, 最大电流 1.4 A)

整个套件包括

- NUCLEO-F302R8
  基于 STM32F302 的控制板。
- X-NUCLEO-IHM07M1
  基于 L6230 的功率板。
- BLDC 电机
- 12V 电源. （仅P-NUCLEO-IHM002包含）



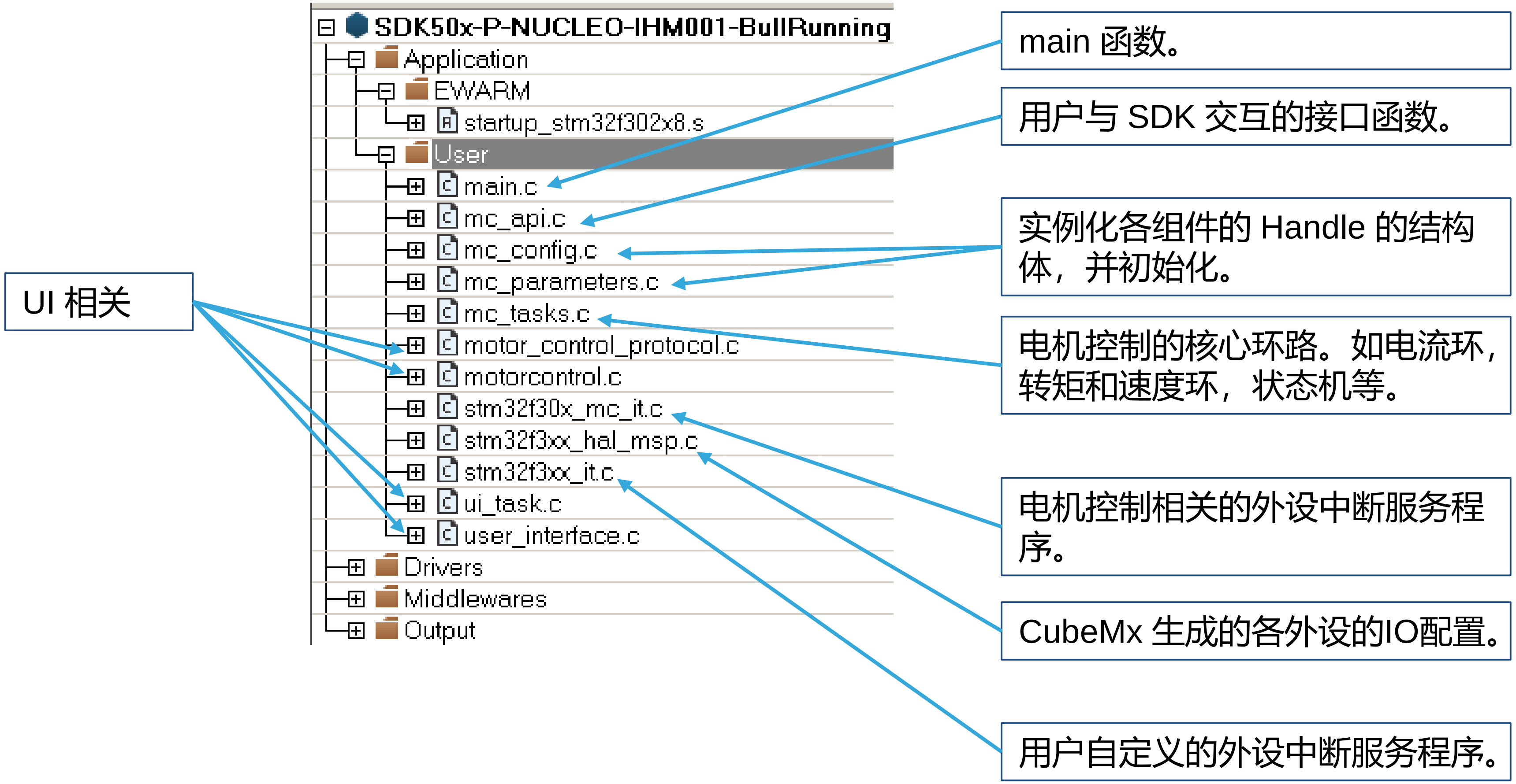
打开 MotorControl Workbench 5.0.3. 在 Example Project 窗口中有很多的例程. 我们来打开 SDK50x-P-NUCLEO-IHM001-BullRunning.stmcx 来生成一个 IAR 的例程代码，然后打开这个工程。



在打开的工程中，有四个文件夹。

- Application.
  和客户的应用紧密相关的程序。通常客户只需要更改这一部分的代码。我们在后面会有更详细的说明。
- Drivers
  MCU 的外设驱动代码，由 CubeMx 生成。另外还包含 ARM 的CMSIS 库.
- Middleware
  电机控制库中的各个组件的代码和库文件。
- Output
  链接器输出的文件如.out文件， .map 文件等。

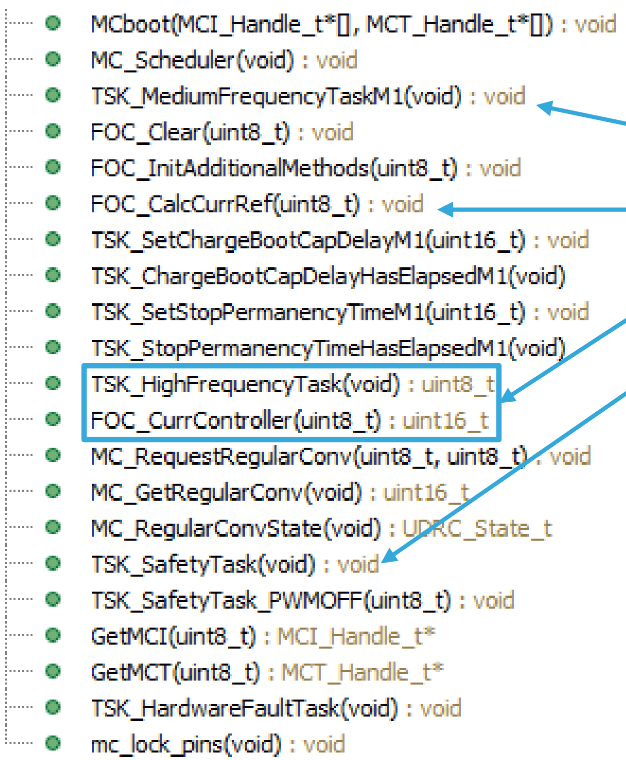
SDK 5.0 软件开发-工程的详细结构



```c
int main(void)
{
  /* USER CODE BEGIN 1 */

  /* USER CODE END 1 */

  /* MCU Configuration----------------------

  /* Reset of all peripherals, Initializes th
  HAL_Init();

  /* USER CODE BEGIN Init */

  /* USER CODE END Init */

  /* Configure the system clock */
  SystemClock_Config();

  /* USER CODE BEGIN SysInit */

  /* USER CODE END SysInit */

  /* Initialize all configured peripherals */
  MX_GPIO_Init();
  MX_ADC1_Init();
  MX_DAC_Init();
  MX_TIM1_Init();
  MX_USART2_UART_Init();
  MX_MotorControl_Init();

  /* Initialize interrupts */
  MX_NVIC_Init();
  /* USER CODE BEGIN 2 */

  /* USER CODE END 2 */

  /* Infinite loop */
  /* USER CODE BEGIN WHILE */
  while (1)
  {

  /* USER CODE END WHILE */

  /* USER CODE BEGIN 3 */

  }
  /* USER CODE END 3 */

}
```

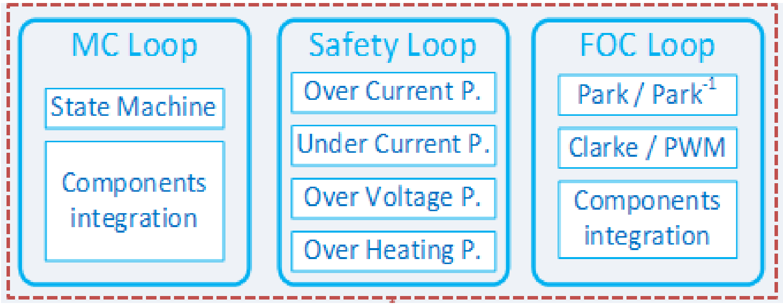
在 main.c 文件中，函数 int main(void) 最重要。它包含以下内容：

- System configure
- Peripherals configure
- Motor Control configure
- Interrupt configure
- Main loop



在文件 mc_tasks.c 中核心的是下面的几个环路:

- MC loop
- Torque or speed loop
- Current loop
- Safety loop



```
ADC1_IRQHandler(void) : void
ADC3_IRQHandler(void) : void
ADC4_IRQHandler(void) : void
TIM1_UP_TIM16_IRQHandler(void) : void
TIM1_BRK_TIM15_IRQHandler(void) : void
USART2_IRQHandler(void) : void
HardFault_Handler(void) : void
SysTick_Handler(void) : void
```

```c
void SysTick_Handler(void)
{
  /* USER CODE BEGIN SysTick_IRQn 0 */

  /* USER CODE END SysTick_IRQn 0 */
  HAL_IncTick();
  HAL_SYSTICK_IRQHandler();
  /* USER CODE BEGIN SysTick_IRQn 1 */
  /* USER CODE END SysTick_IRQn 1 */
    TB_Scheduler();
  /* USER CODE BEGIN SysTick_IRQn 2 */
  /* USER CODE END SysTick_IRQn 2 */
}

/* USER CODE BEGIN 1 */

/* USER CODE END 1 */
```

在文件 stm32f30x_mc_it.c 中有以下的中断服务程序：

- ADC 中断：HighFrequencyTask() 在这个函数中被调用。调用的频率可以在 workbench 中设定。最大的频率可以和 PWM 频率相同。
- 此例程中未启用。
- TIM1 Break 中断。
- UART 中断。
- System hard fault 中断。
- System Tick 中断：周期为 500us。

SDK 5.0 软件开发-工程的详细结构

```
pMCI : MCI_Handle_t*[]
MC_StartMotor1(void)
MC_StopMotor1(void) : void
MC_ProgramSpeedRampMotor1(int16_t, uint16_t) : void
MC_ProgramTorqueRampMotor1(int16_t, uint16_t) : void
MC_SetCurrentReferenceMotor1(Curr_Components) : void
MC_GetCommandStateMotor1(void) : MCI_CommandState_t
MC_StopSpeedRampMotor1(void)
MC_HasRampCompletedMotor1(void)
MC_GetMecSpeedReferenceMotor1(void) : int16_t
MC_GetMecSpeedAverageMotor1(void) : int16_t
MC_GetLastRampFinalSpeedMotor1(void) : int16_t
MC_GetControlModeMotor1(void) : STC_Modality_t
MC_GetImposedDirectionMotor1(void) : int16_t
MC_GetSpeedSensorReliabilityMotor1(void)
MC_GetPhaseCurrentAmplitudeMotor1(void) : int16_t
MC_GetPhaseVoltageAmplitudeMotor1(void) : int16_t
MC_GetIabMotor1(void) : Curr_Components
MC_GetIalphabetaMotor1(void) : Curr_Components
MC_GetIqdMotor1(void) : Curr_Components
MC_GetIqdrefMotor1(void) : Curr_Components
MC_GetVqdMotor1(void) : Volt_Components
MC_GetValphabetaMotor1(void) : Volt_Components
MC_GetElAngledppMotor1(void) : int16_t
MC_GetTerefMotor1(void) : int16_t
MC_SetIdrefMotor1(int16_t) : void
MC_Clear_IqdrefMotor1(void) : void
MC_AcknowledgeFaultMotor1(void)
MC_GetOccurredFaultsMotor1(void) : uint16_t
MC_GetCurrentFaultsMotor1(void) : uint16_t
MCI_GetSTMStateMotor1(void) : State_t
MC_ProgramRegularConversion(uint8_t, uint8_t) : void
MC_GetRegularConversionValue(void) : uint16_t
MC_GetRegularConversionState(void) : UDRC_State_t
```

在 mc_api.c 中有一系列的函数来实现与对电机的控制，我们称之为 MC API 。这些函数是用户和 SDK 之间的桥梁。下面列出了一些最常用的函数:

- MC_StartMotor1
- MC_StopMotor1
- MC_ProgramSpeedRampMotor1
- MC_ProgramTorqueRampMotor1
- MC_GetMecSpeedReferenceMotor1
- MC_GetMecSpeedAverageMotor1
- MCI_GetSTMStateMotor1
- MC_GetOccurredFaultsMotor1
- MC_AcknowledgeFaultMotor1
- MC_GetImposedDirectionMotor1

life.augmented

STM32 Motor Control SDK 可以用一片 STM32 MCU 同时驱动两台电机。为了简化程序 MC API 为每一台电机提供了一组单独的函数。这样把函数的参数限制到最简化。我们从函数的名字可以看出它是用来控制哪个电机的. 这是与 SDK 4.3 最主要的不同.

SDK 4.3	SDK 5.0
bool MCI_StartMotor(CMCI this)	bool MC_StartMotor1(void) bool MC_StartMotor2(void)
CMCI oMCI[MC_NUM]; MCboot(oMCI,oMCT) MCI_StartMotor(oMCI[M1])	Directly call function MC_StartMotor1()

如果 Motor 1 的状态机正处于 IDLE 状态, 命令被立即执行启动电机，返回值为 true。否则命令被丢弃，返回值为 false。调用者可以检查返回值来得知命令是被执行还是被丢弃。

```
bool MC_StartMotor1(void)
{
return MCI_StartMotor(
pMCI[M1] );
}
```

如果 Motor 1 的状态机正处于 RUN 或者 START 状态, 命令被立即执行停止电机。否则命令被丢弃。

```
void MC_StopMotor1(void)
{
MCI_StopMotor( pMCI[M1] );
}
```

life.augmented

设置速度指令。．在调用此函数后速度指令在 hDurationms 设置的时间内由当前速度变化到 hFinalSpeed 设置的目标速度。

```
void MC_ProgramSpeedRampMotor1( int16_t hFinalSpeed, uint16_t hDurationms )
{
    MCI_ExecSpeedRamp( pMCI[M1], hFinalSpeed, hDurationms );
}
```

设置转矩指令。在调用此函数后转矩指令在 hDurationms 设置的时间内由当前转矩变化到 hFinalTorque 设置的目标转矩。

```
void MC_ProgramTorqueRampMotor1( int16_t hFinalTorque, uint16_t hDurationms )
{
    MCI_ExecTorqueRamp( pMCI[M1], hFinalTorque, hDurationms );
}
```

life.augmented

返回 Motor 1 转子当前的指令机械转速, 数字量1代表0.1Hz。

```
int16_t MC_GetMecSpeedReferenceMotor1(void)
{
    return MCI_GetMecSpeedRef01Hz( pMCI[M1] );
}
```

返回 Motor 1 转子当前实测的平均机械转速, 数字量1代表0.1Hz。

```
int16_t MC_GetMecSpeedAverageMotor1(void)
{
    return MCI_GetAvrgMecSpeed01Hz( pMCI[M1] );
}
```

返回 Motor 1 状态机当前的状态。下面表格列举了一些常用的电机状态。

```
State_t  MCI_GetSTMStateMotor1(void)
{
    return MCI_GetSTMState( pMCI[M1] );
}
```

Frequently used state

State	Code	Simple Description
IDLE	0	Idle
START	4	In start up process
START_RUN	5	In start up process
RUN	6	Run normal
ANY_STOP	7	Stop
STOP	8	Stop
STOP_IDLE	9	Stop
FAULT_NOW	10	Fault
FAULT_OVER	11	Fault

life.augmented

返回 Motor 1 发生过的故障的代码。

```
uint16_t MC_GetOccurredFaultsMotor1(void)
{
    return MCI_GetOccurredFaults( pMCI[M1] );
}
```

Fault List

State	Code	Simple Description
MC_NO_ERROR	0x0000	No fault
MC_NO_FAULTS	0x0000	No fault
MC_FOC_DURATION	0x0001	FOC calculation time out
MC_OVER_VOLT	0x0002	Bus over voltage
MC_UNDER_VOLT	0x0004	Bus under voltage
MC_OVER_TEMP	0x0008	Over temperature
MC_START_UP	0x0010	Start up failure
MC_SPEED_FDBK	0x0020	Speed feedback is not reliable
MC_BREAK_IN	0x0040	Hardware break in
MC_SW_ERROR	0x0080	Software fault

应答 Motor 1 发生过的故障。用户调用这个函数前，如果电机发生了故障。电机将停留在FAULT_OVER 状态，并保留故障代码。在调用了这个函数之后，状态机将清除故障代码的记录，并恢复到 IDLE 状态。

```
bool MC_AcknowledgeFaultMotor1( void )
{
    return MCI_FaultAcknowledged( pMCI[M1] );
}
```

返回由最后一个指令设置的Motor 1的方向。如果最终的速度或转矩指令为负函数返回 -1，否则函数返回 1 。

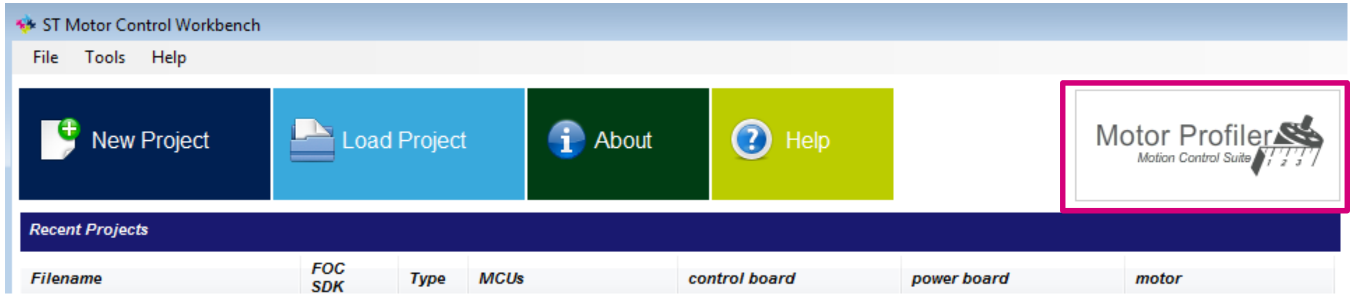
```
int16_t MC_GetImposedDirectionMotor1(void)
{
    return MCI_GetImposedMotorDirection( pMCI[M1] );
}
```

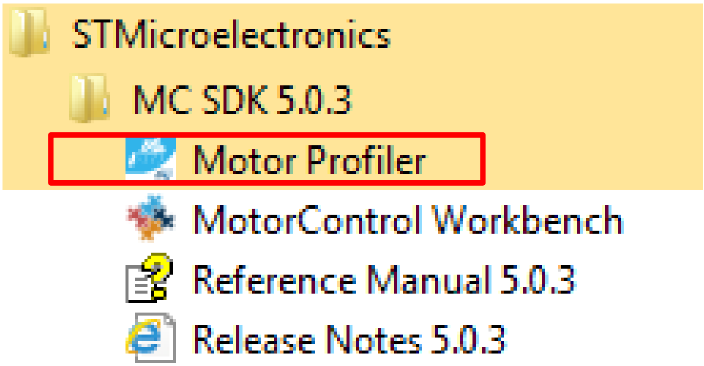
3.实验1：MC SDK5.0 电动机参数识别

电机参数测量

可通过下列方式打开ST电机参数测量工具:

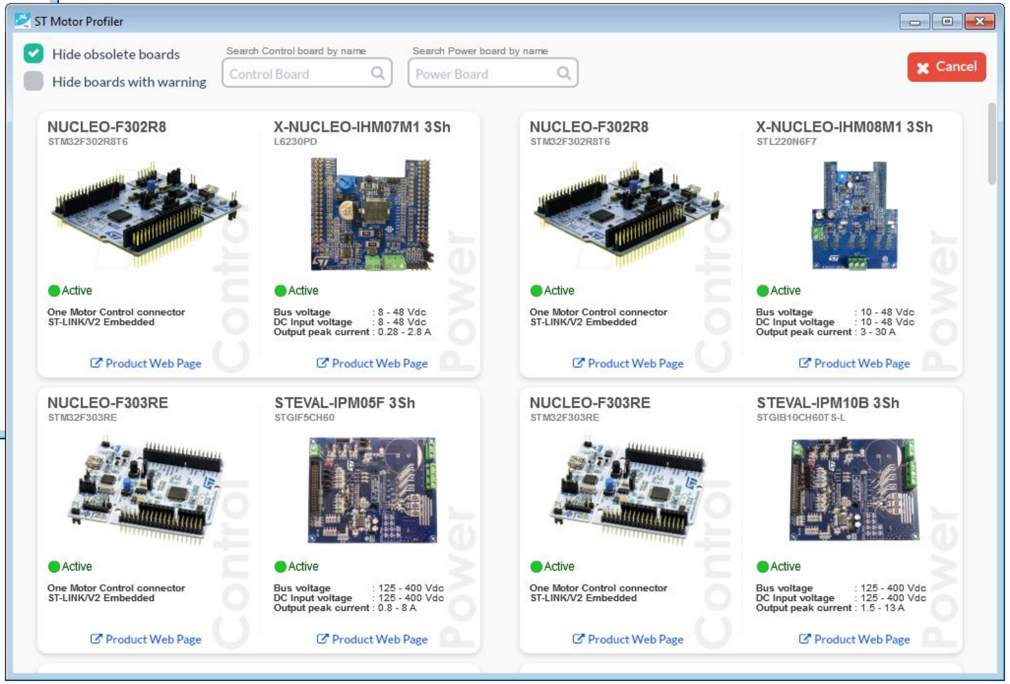
- 使用ST MC Workbench GUI上的专用按钮
- 直接从安装文件夹运行



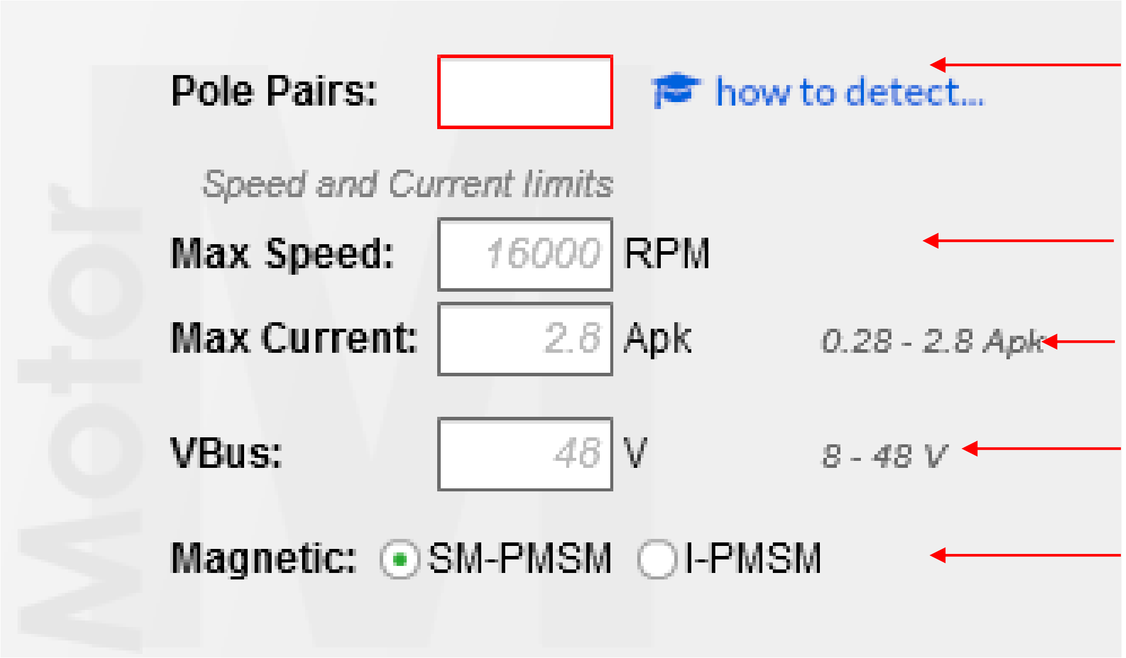


电机参数测量

硬件搭配示例列表



SM-PMSM参数示例



电机极对数 (必填)

电机最大转速 (可选)

电机允许的最大电流 (可选)

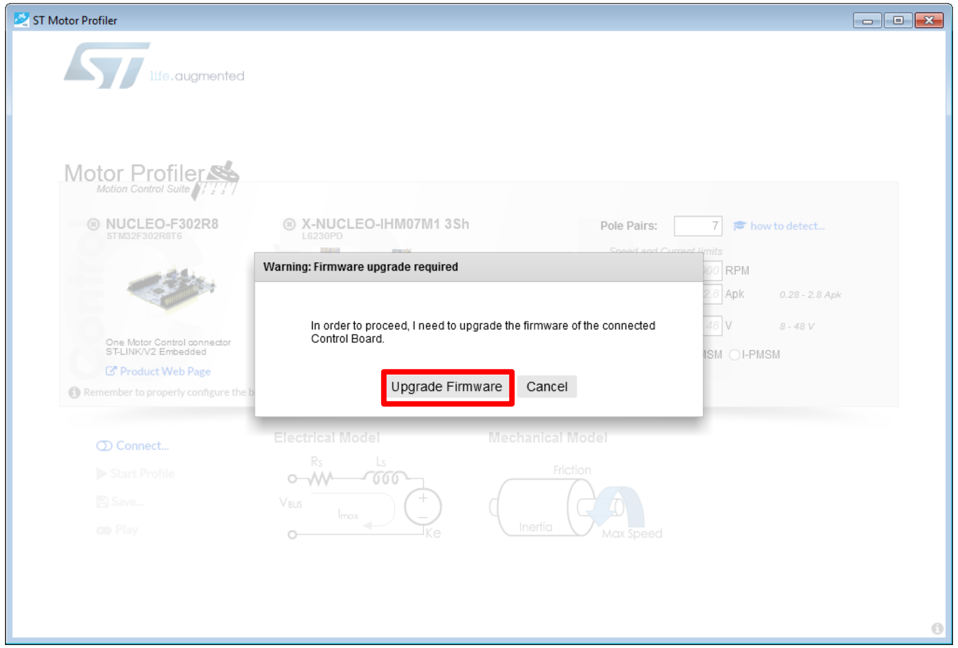
额定总线电压 (可选)

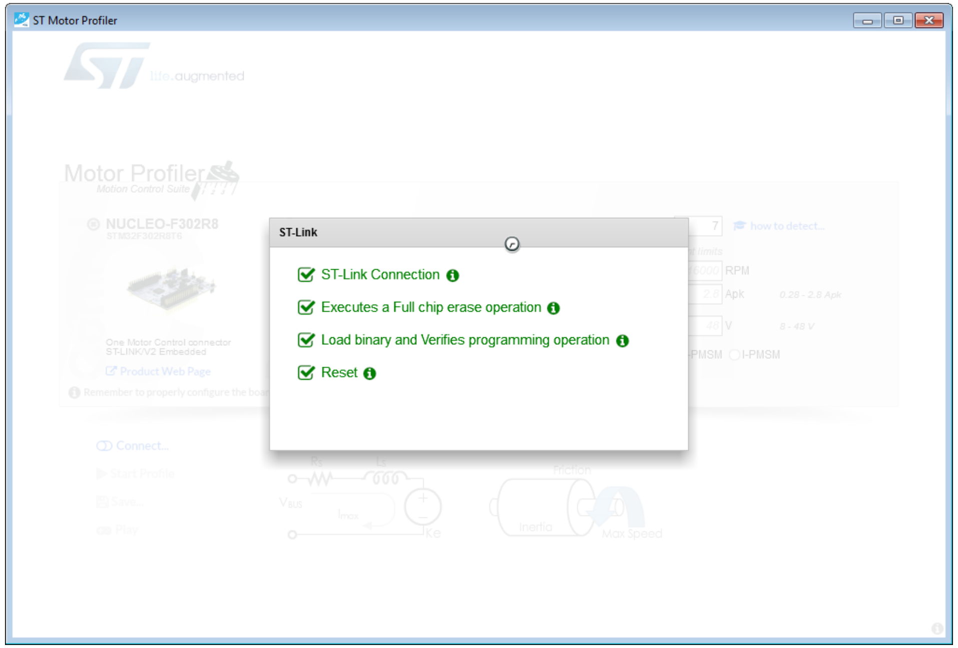
磁体内置类型 (必填)

life.augmented

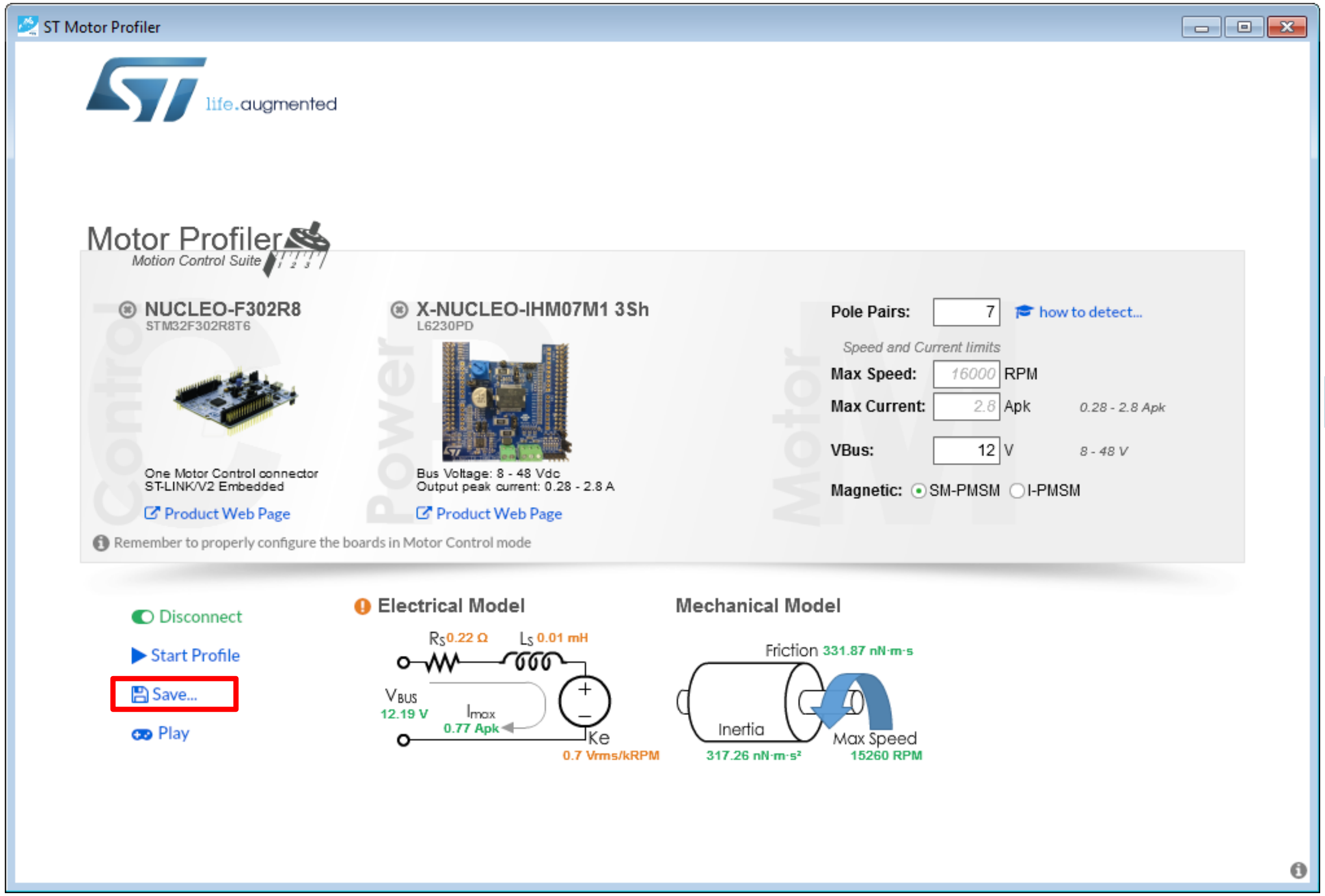
电机参数测量

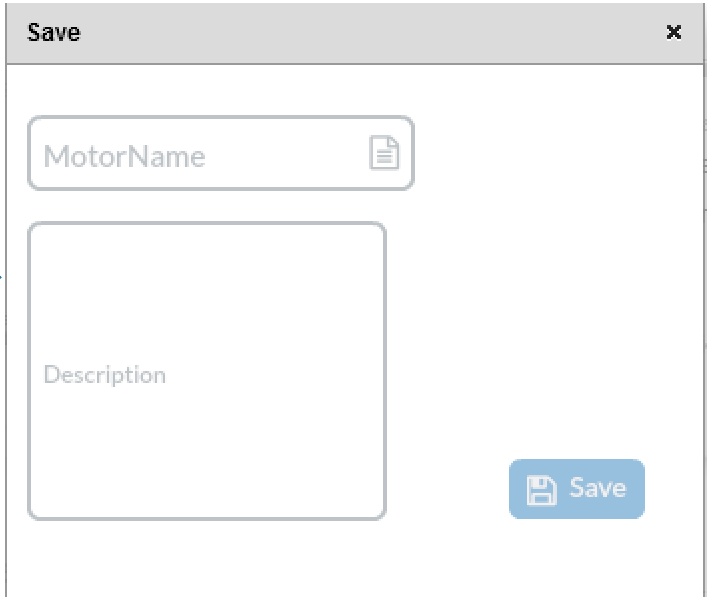
如需更新固件：





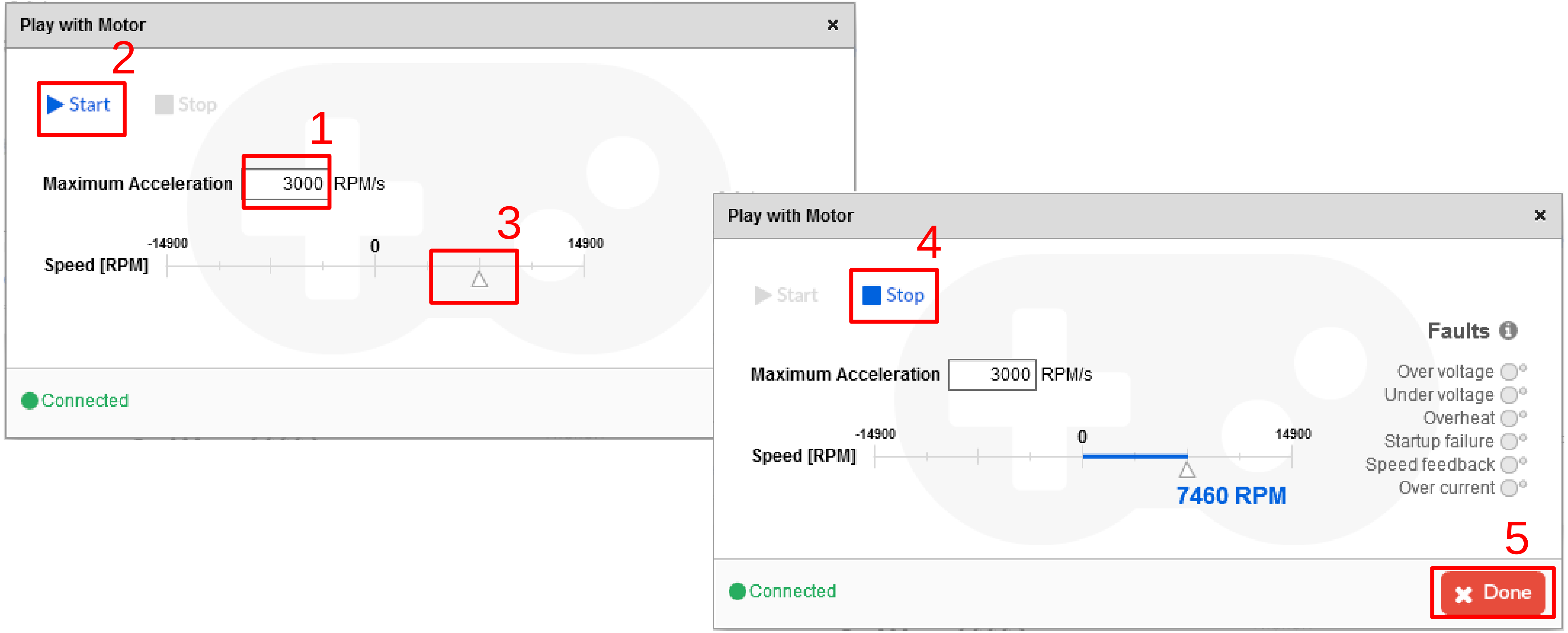
测量结果：





life.augmented

点击*Play*按钮可转动测量过的电机



4 .MC SDK5.0 工具链及图形用户界面

目录

- **MC SDK5.0 培训材料(IDE/GUI)**
- 软件工具的下载和安装
- ST MC Workbench
- MC Project 的生成，编译和下载
- 电机控制及监控
- Workbench 关键配置参数
- 电机参数测量

life.augmented

软件工具的安装

请预先安装下列PC软件工具：

- ST MC Workbench (v5.0.3)
- STM32CubeMx (v4.25)
- ST-LINK/V2 (v4.2.0)
- IDE:
  - IAR Embedded Workbench for Arm (v8.xx)
    http://www.iar.com/

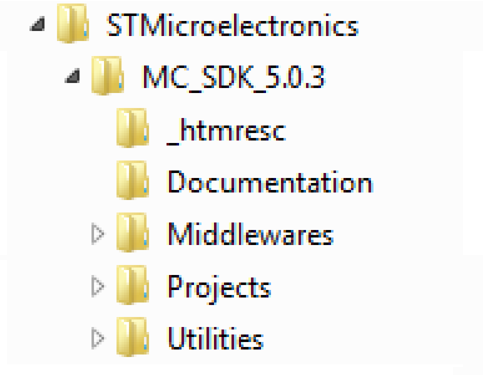
STM32CubeMx请不要安装在中文路径下！！

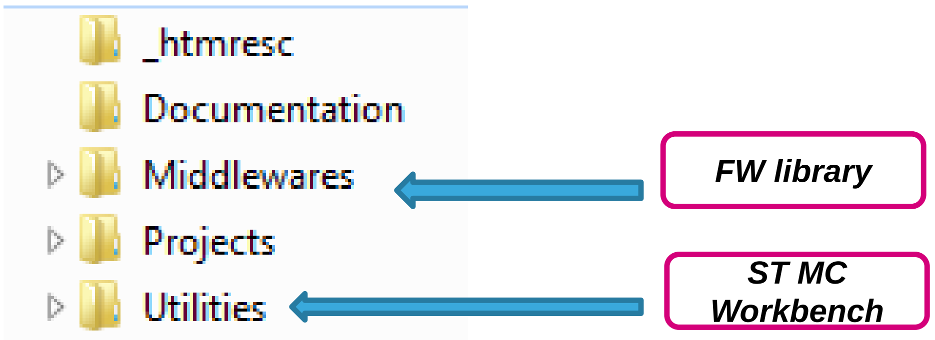
ST MC Workbench 的安装

请从上www.st.com下载STM32 MC SDK，并安装。

STM32 MC SDK 固件 (X-CUBE-MCSDK and X-CUBE-MCSDK-FUL) 包括PMSM 固件库(FOC控制) 和STM32 MC Workbench。

安装后，可以看到下列文件夹：





ST MC Workbench 相关文档

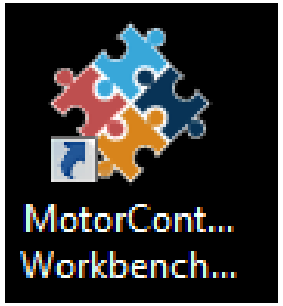
可从www.st.com上获得STMicroelectronics的文档：

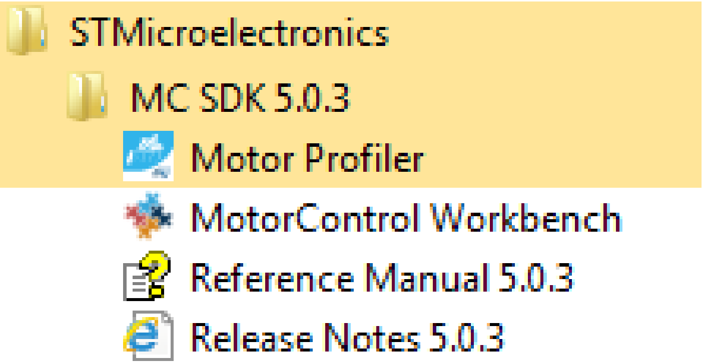
Title	Type	Contents
DB3548: STM32 MC SDK software expansion for STM32Cube	Data Brief	数据手册。MC SDK5.0作为CubeMX的一个扩展软件包。
UM2374: Getting started with STM32 motor control SDK v5.0	User Manual	MC SDK5.0入门手册
UM2380: STM32 motor control SDK v5.0 tools	User Manual	MC SDK5.0 外部工具(对应CubeMX而言)
AN5143: How to migrate motor control application software from SDK v4.3 to SDK v5.0	Application note	介绍如何从SDK4.3转到SDK5.0。
UM2312: Development checklist for STM32Cube Expansion Packages	User Manual	STMCube扩展软件包开发相关标准一览表
UM2285: Development guidelines for STM32Cube Expansion Packages	User Manual	STM32Cube 开发指导
UM1718: STM32CubeMx for STM32 configuration and initialization C code generation user manual	User Manual	STM32Cube 入门手册
UM0892: STM32 ST-LINK utility software description user manual	User Manual	STM32 ST-LINK用户手册

软件启动

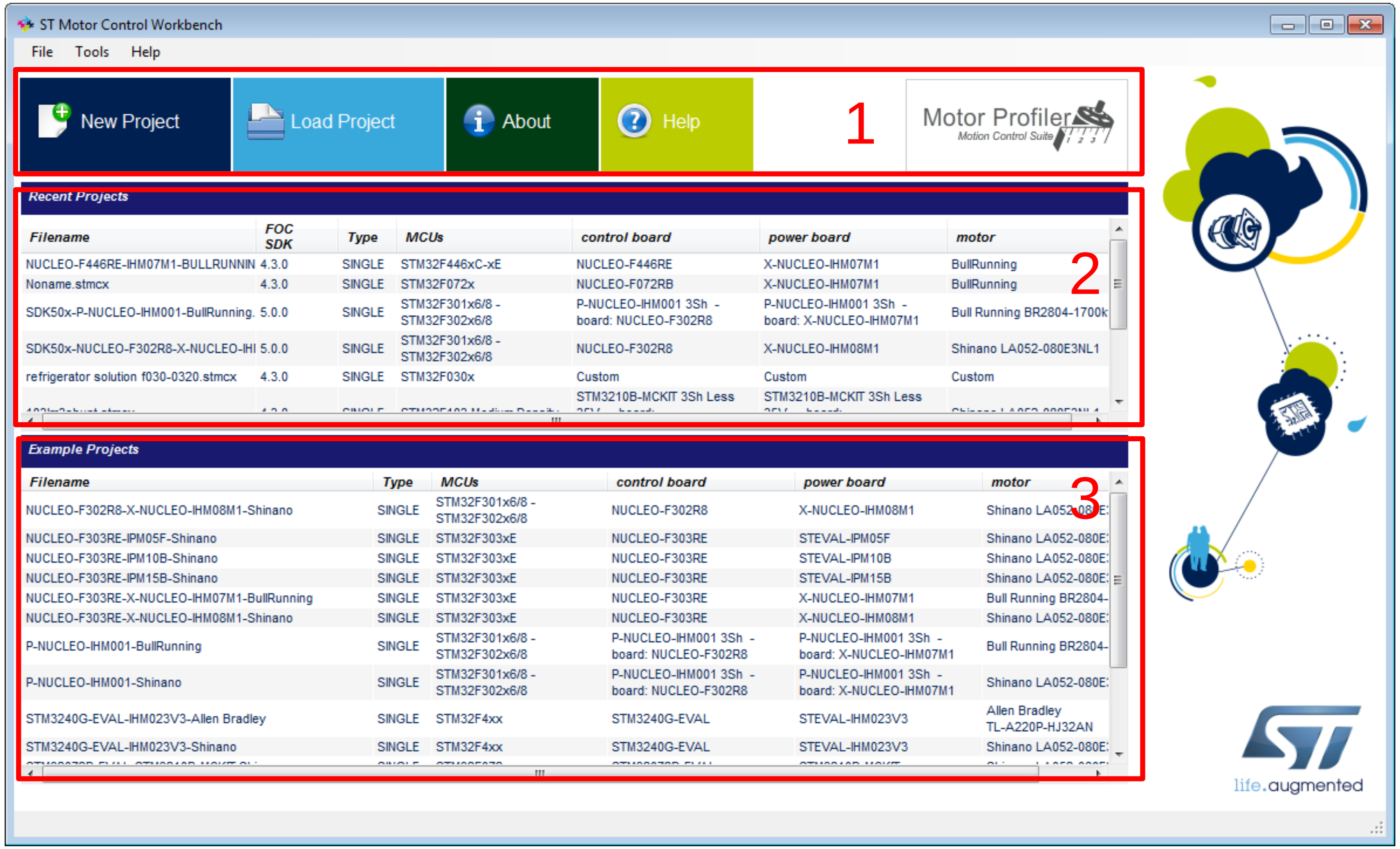
下列方式可启动ST MC Workbench软件工具：

- 单击其图标
- 从安装文件夹路径直接启动





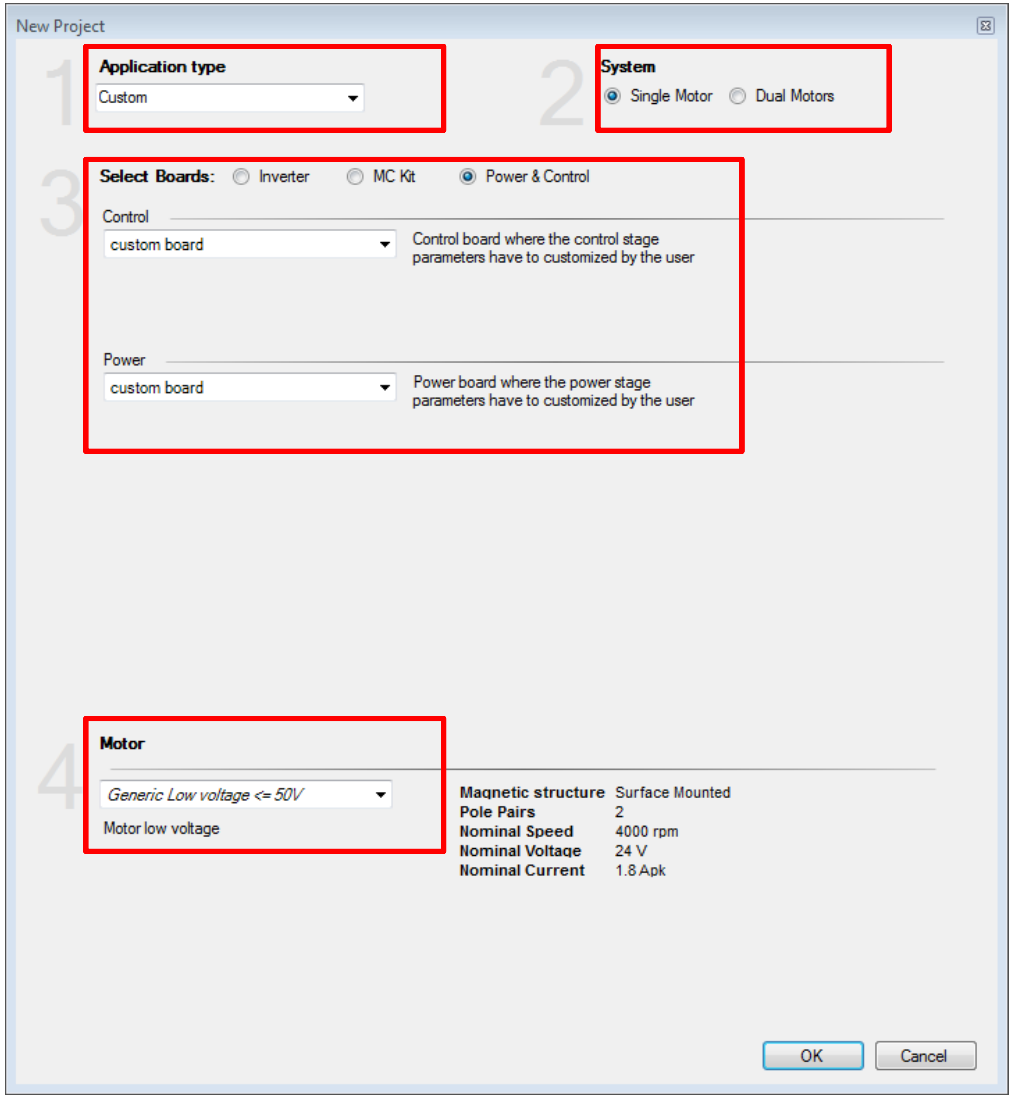
Workbench

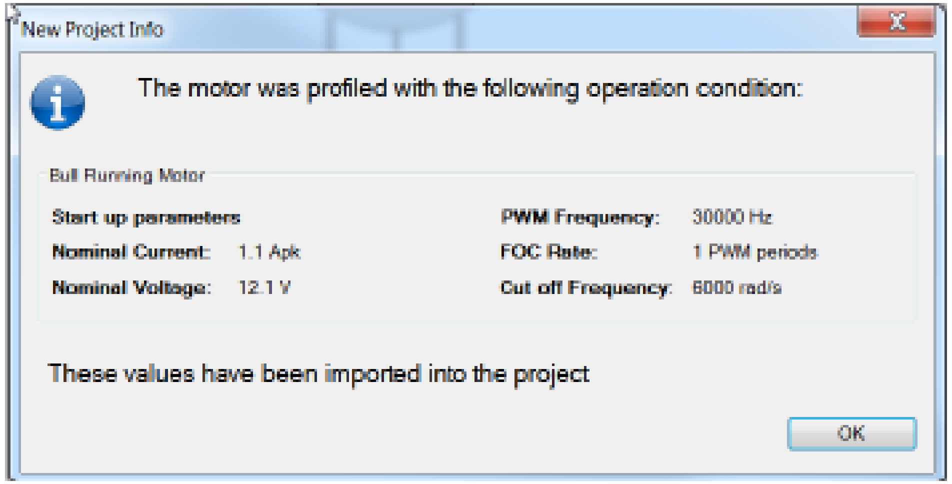


1. 用户按钮区用于创建新工程，加载已有工程或启动ST电机参数测量工具。
2. 最近的工程区用于加载近期的工程。
3. 例程区用于加载工程示例。

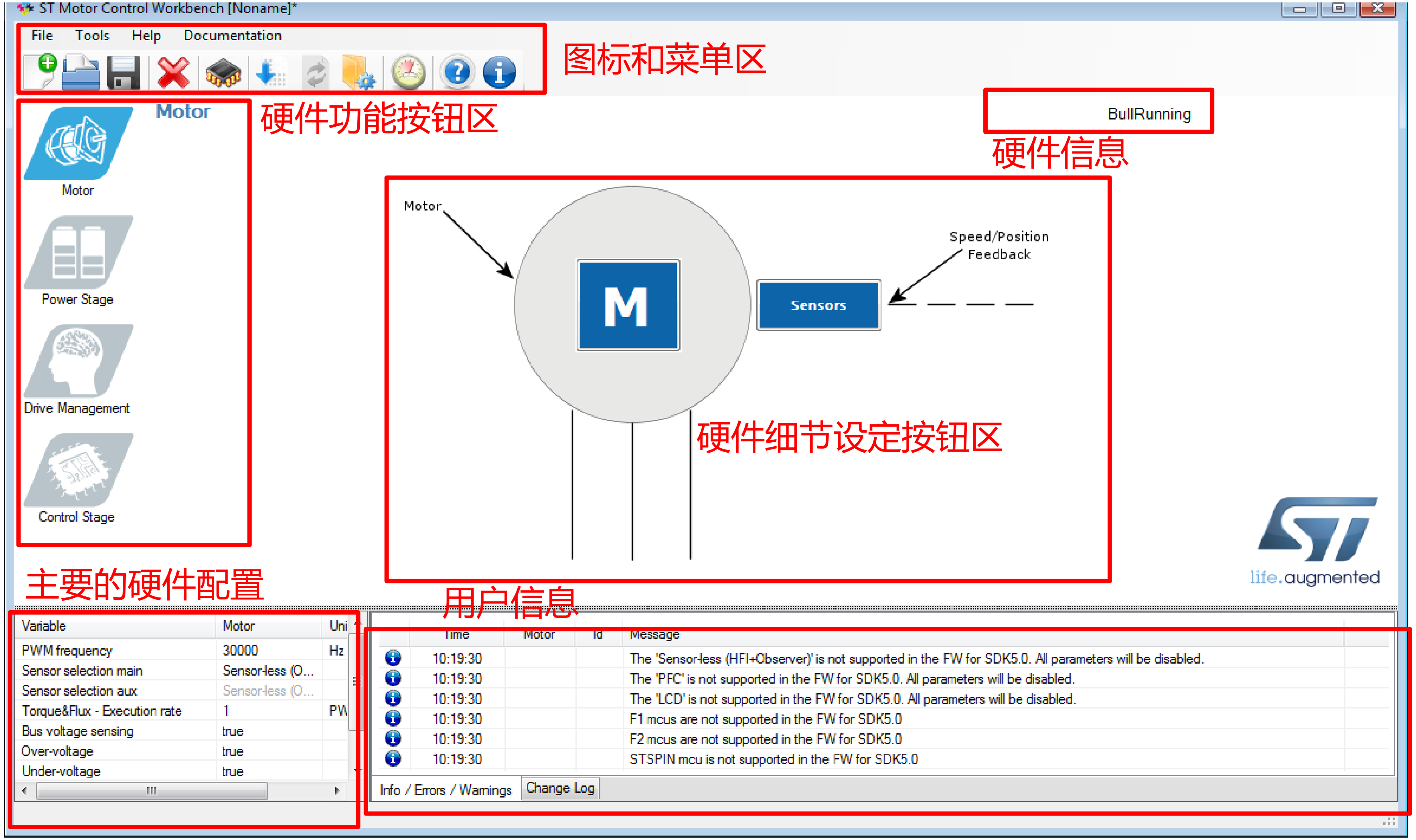
life.augmented

创建新工程


New Project
1
Application type
Custom
2
System
Single Motor
Dual Motors
3
Select Boards:
Inverter
MC Kit
Power & Control
Control
custom board
Control board where the control stage parameters have to customized by the user
Power
custom board
Power board where the power stage parameters have to customized by the user
4
Motor
Generic Low voltage <= 50V
Motor low voltage
Magnetic structure Surface Mounted
Pole Pairs 2
Nominal Speed 4000 rpm
Nominal Voltage 24 V
Nominal Current 1.8 Apk
OK
Cancel

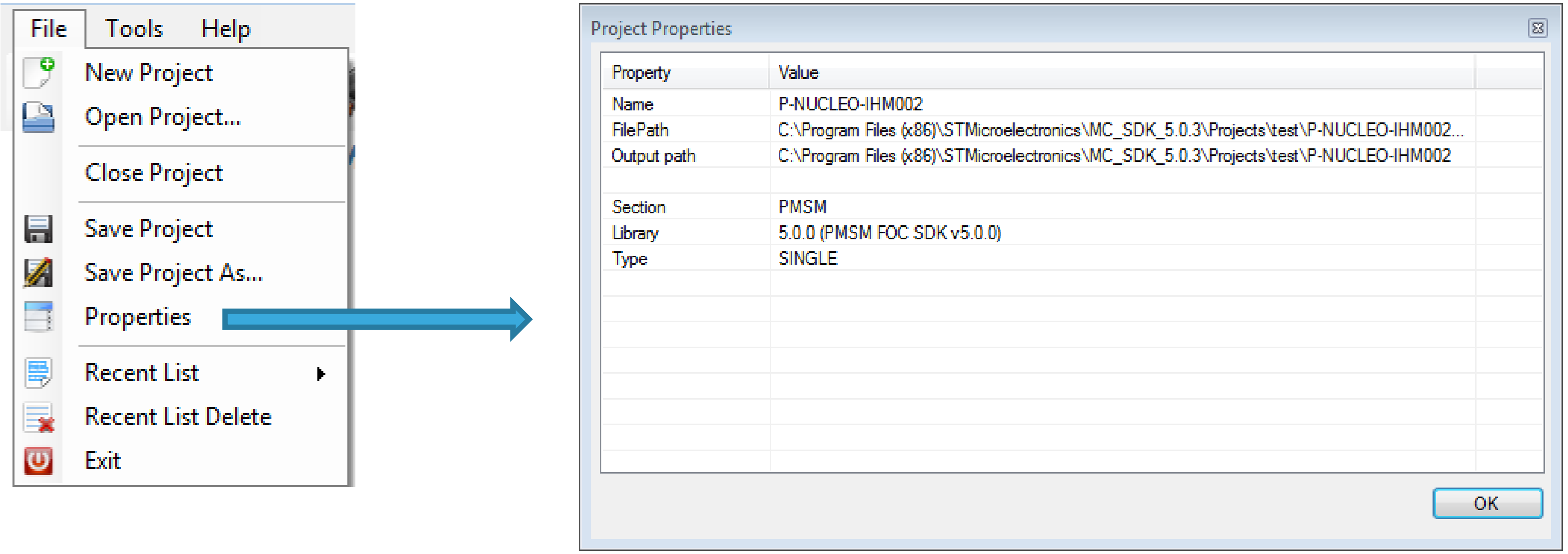

New Project Info
The motor was profiled with the following operation condition:
Bull Running Motor
Start up parameters
Nominal Current: 1.1 Apk
Nominal Voltage: 12.1 V
PWM Frequency: 30000 Hz
FOC Rate: 1 PWM periods
Cut off Frequency: 6000 rad/s
These values have been imported into the project
OK

硬件配置窗口



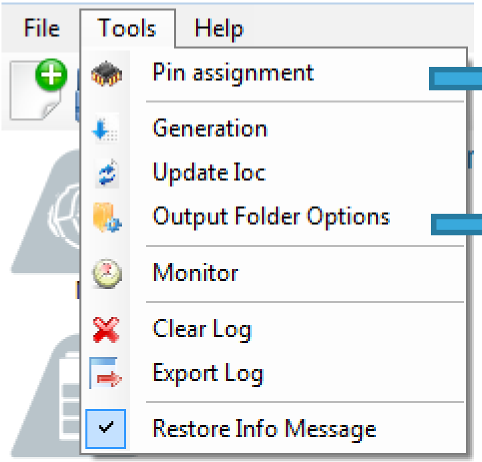
ST Motor Control Workbench [Noname]*
File Tools Help Documentation
图标和菜单区
Motor
硬件功能按钮区
Motor
Power Stage
Drive Management
Control Stage
BullRunning
硬件信息
Motor
M
Sensors
Speed/Position Feedback
硬件细节设定按钮区
life.augmented
主要的硬件配置
用户信息
Variable | Motor | Uni
PWM frequency | 30000 | Hz
Sensor selection main | Sensor-less (O...
Sensor selection aux | Sensor-less (O...
Torque&Flux - Execution rate | 1 | PW
Bus voltage sensing | true
Over-voltage | true
Under-voltage | true
Time | Motor | Id | Message
10:19:30 The 'Sensor-less (HFI+Observer)' is not supported in the FW for SDK5.0. All parameters will be disabled.
10:19:30 The 'PFC' is not supported in the FW for SDK5.0. All parameters will be disabled.
10:19:30 The 'LCD' is not supported in the FW for SDK5.0. All parameters will be disabled.
10:19:30 F1 mcus are not supported in the FW for SDK5.0
10:19:30 F2 mcus are not supported in the FW for SDK5.0
10:19:30 STSPIN mcu is not supported in the FW for SDK5.0
Info / Errors / Warnings
Change Log

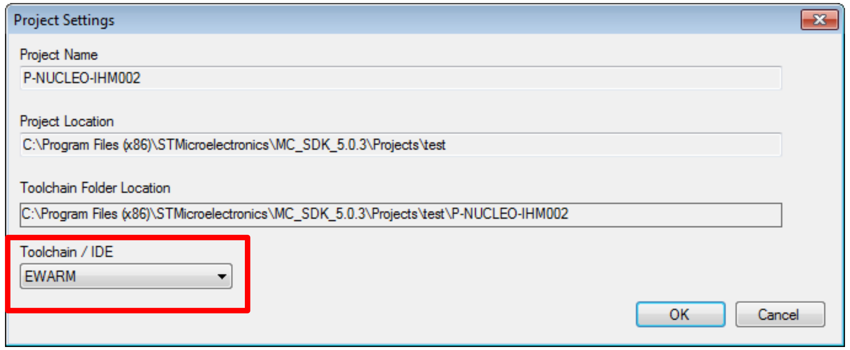
Workbench菜单 (1)

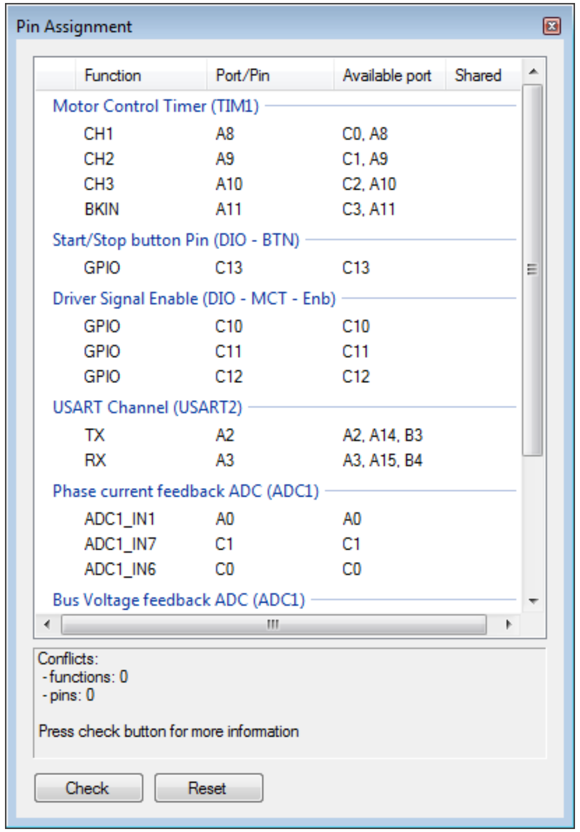


- ✓ New Project: 创建一个新工程
- ✓ Open Project…: 打开一个现有的工程
- ✓ Close Project: 关闭现在的工程
- ✓ Save Project: 使用相同文件名保存打开的工程
- ✓ Save Project As…: 将打开的工程保存为指定的文件名
- ✓ Properties: 查看工程属性
- ✓ Recent List: 从最近打开过的工程列表中加载一个现有工程
- ✓ Recent List Delete: 删除最近的工程列表
- ✓ Exit: 从硬件配置窗口退出

Workbench菜单 (2)







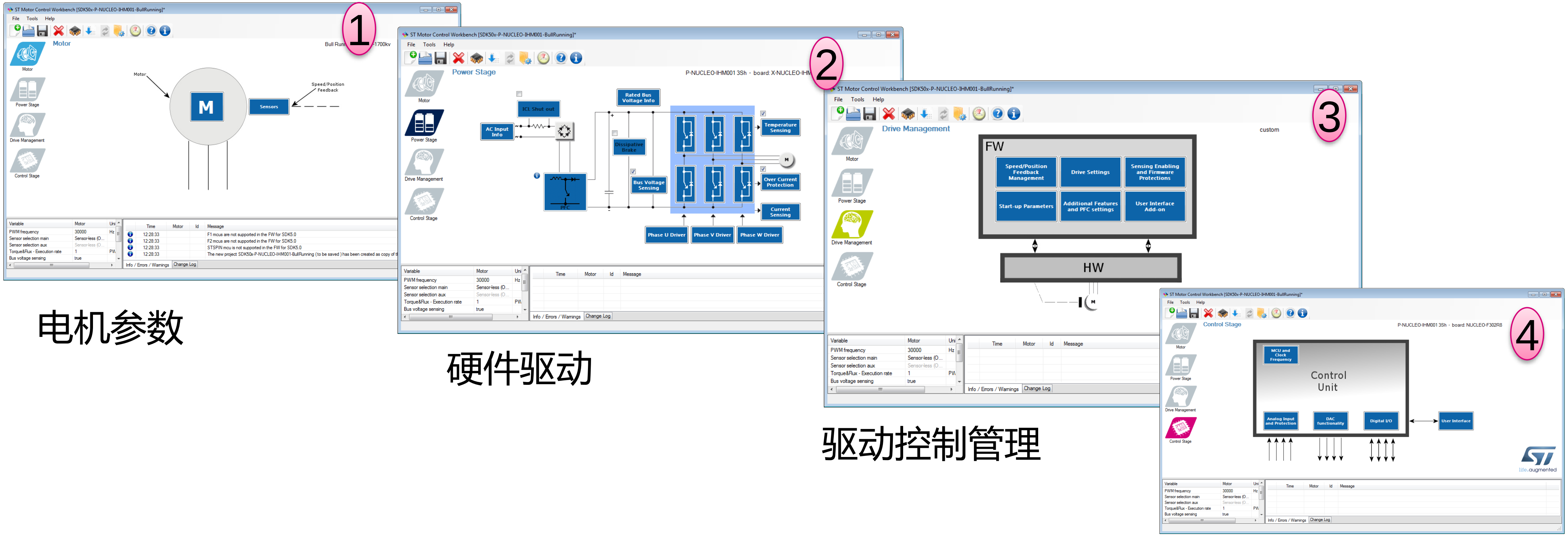
- ✓ Pin assignment:检查MCU的引脚分配和剩余的可用引脚
- ✓ Generation:根据所选的IDE，生成MC应用工程文件
- ✓ Update ioc:更新当前工程的.ioc文件，仅限FW参数，不包含硬件配置
- ✓ Output Folder Option:建立工程环境的路径
- ✓ Monitor:监控并转动电机
- ✓ Clear Log:清除用户信息表
- ✓ Export Log: 将用户信息表以文本格式导出到日志文件
- ✓ Restore Info Message: 需要时显示用户信息表

工具栏图标

- ✓ New：创建一个新工程
- ✓ Load：打开一个现有的工程
- ✓ Save：使用相同文件名保存打开的工程
- ✓ Clear Log：清除用户信息表
- ✓ Pin assignment ： 检查MCU的引脚分配和剩余的可用引脚
- ✓ Generation: 根据所选的IDE，生成MC应用工程文件
- ✓ Update Ioc: 更新当前工程的.ioc文件，仅限FW参数，不包含硬件配置
- ✓ Output Folder Option: 建立工程环境的路径.
- ✓ Click to open monitor: 监控并转动电机
- ✓ Help: 提供在线帮助文件的访问接口
- ✓ About: 显示该应用的版本号

Workbench

根据客户需求快速设置电机库



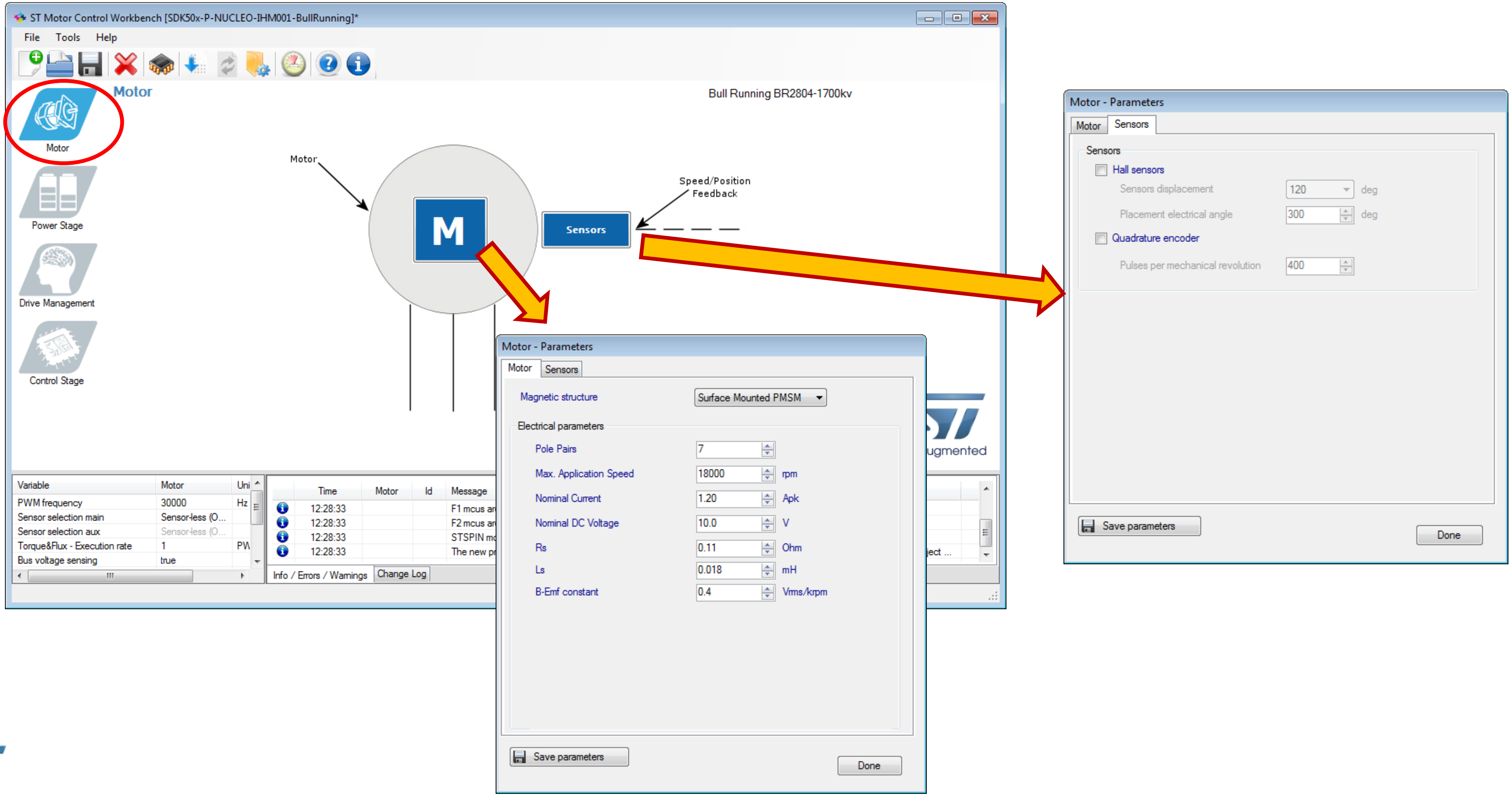
电机参数

硬件驱动

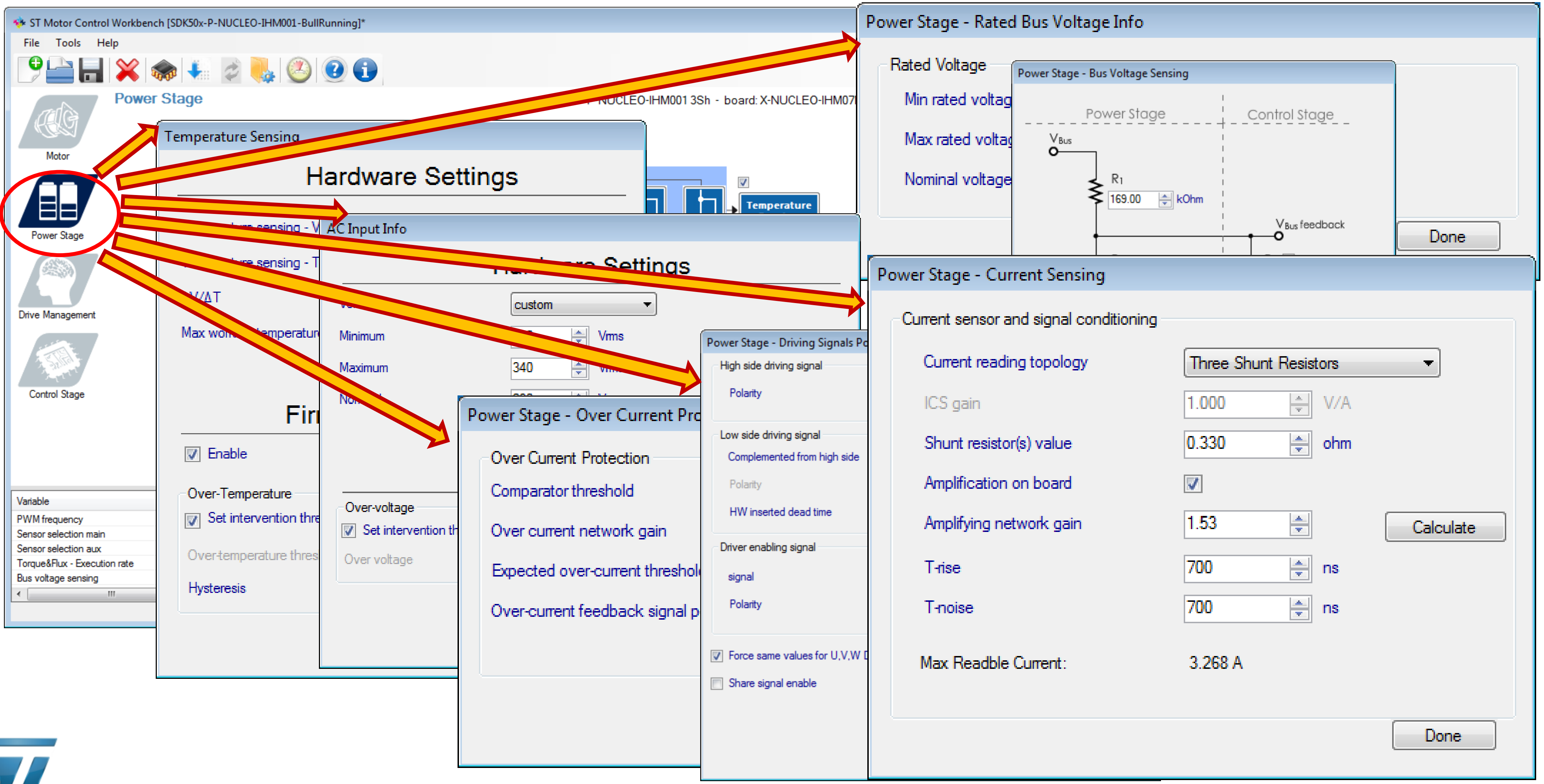
驱动控制管理

单片机相关

电机参数


ST Motor Control Workbench [SDK50x-P-NUCLEO-IHM001-BullRunning]*
File Tools Help
Motor
Bull Running BR2804-1700kv
Motor
Power Stage
Drive Management
Control Stage
Motor
M
Sensors
Speed/Position Feedback
Motor - Parameters
Motor Sensors
Magnetic structure Surface Mounted PMSM
Electrical parameters
Pole Pairs 7
Max. Application Speed 18000 rpm
Nominal Current 1.20 Apk
Nominal DC Voltage 10.0 V
Rs 0.11 Ohm
Ls 0.018 mH
B-Emf constant 0.4 Vrms/krpm
Save parameters
Done
Motor - Parameters
Motor Sensors
Sensors
Hall sensors
Sensors displacement 120 deg
Placement electrical angle 300 deg
Quadrature encoder
Pulses per mechanical revolution 400
Save parameters
Done
Variable Motor
PWM frequency 30000 Hz
Sensor selection main Sensor-less (O...
Sensor selection aux Sensor-less (O...
Torque&Flux - Execution rate 1
Bus voltage sensing true
Time Motor Id Message
12:28:33 F1 mcus ar
12:28:33 F2 mcus ar
12:28:33 STSPIN m
12:28:33 The new p
Info / Errors / Warnings
Change Log

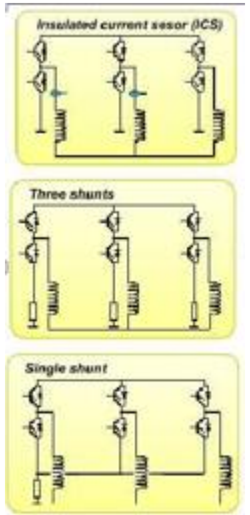
硬件驱动

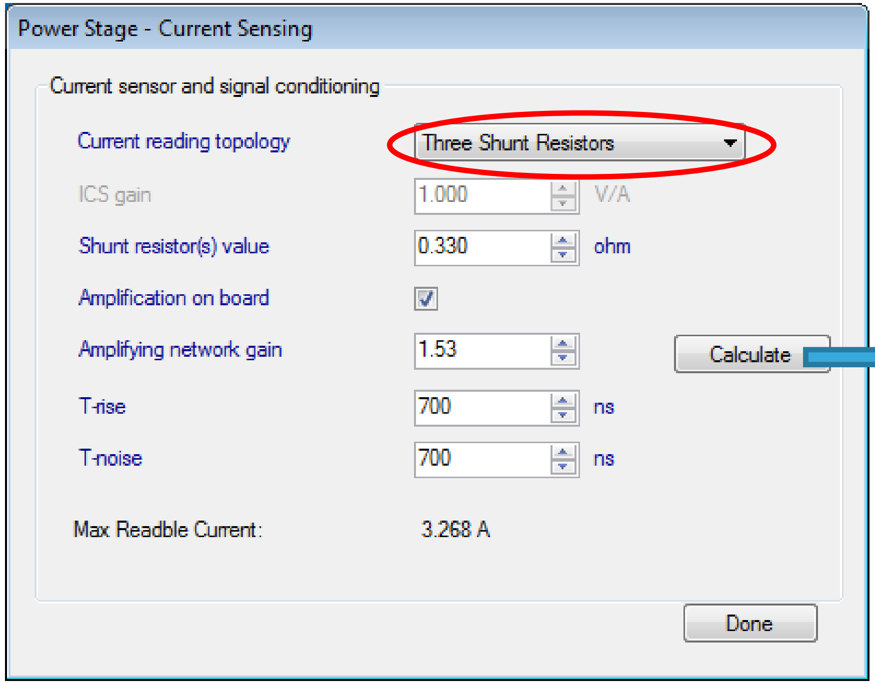


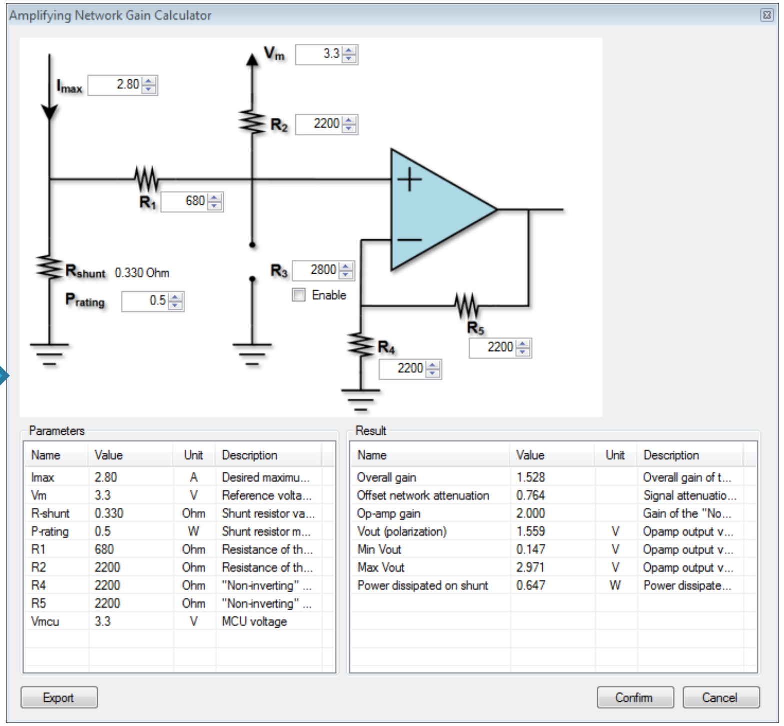
ST Motor Control Workbench [SDK50x-P-NUCLEO-IHM001-BullRunning]*
File Tools Help
Power Stage
Motor
Power Stage
Drive Management
Control Stage
Variable
PWM frequency
Sensor selection main
Sensor selection aux
Torque&Flux - Execution rate
Bus voltage sensing
NUCLEO-IHM001 3Sh - board: X-NUCLEO-IHM07
Temperature Sensing
Hardware Settings
Temperature
Enable
Over-Temperature
Set intervention thre
Over-temperature thres
Hysteresis
AC Input Info
custom
Minimum
Maximum
340
Vrms
Over-voltage
Set intervention th
Over voltage
Power Stage - Rated Bus Voltage Info
Rated Voltage
Min rated voltag
Max rated voltag
Nominal voltage
Power Stage - Bus Voltage Sensing
Power Stage
Control Stage
R1
169.00
kOhm
Done
Power Stage - Driving Signals Po
High side driving signal
Polarity
Low side driving signal
Complemented from high side
Polarity
HW inserted dead time
Driver enabling signal
signal
Polarity
Force same values for U,V,W D
Share signal enable
Power Stage - Over Current Pro
Over Current Protection
Comparator threshold
Over current network gain
Expected over-current threshol
Over-current feedback signal p
Power Stage - Current Sensing
Current sensor and signal conditioning
Current reading topology
Three Shunt Resistors
ICS gain
1.000
V/A
Shunt resistor(s) value
0.330
ohm
Amplification on board
Amplifying network gain
1.53
Calculate
T-rise
700
ns
T-noise
700
ns
Max Readble Current:
3.268 A
Done

电流采样拓扑结构选择：

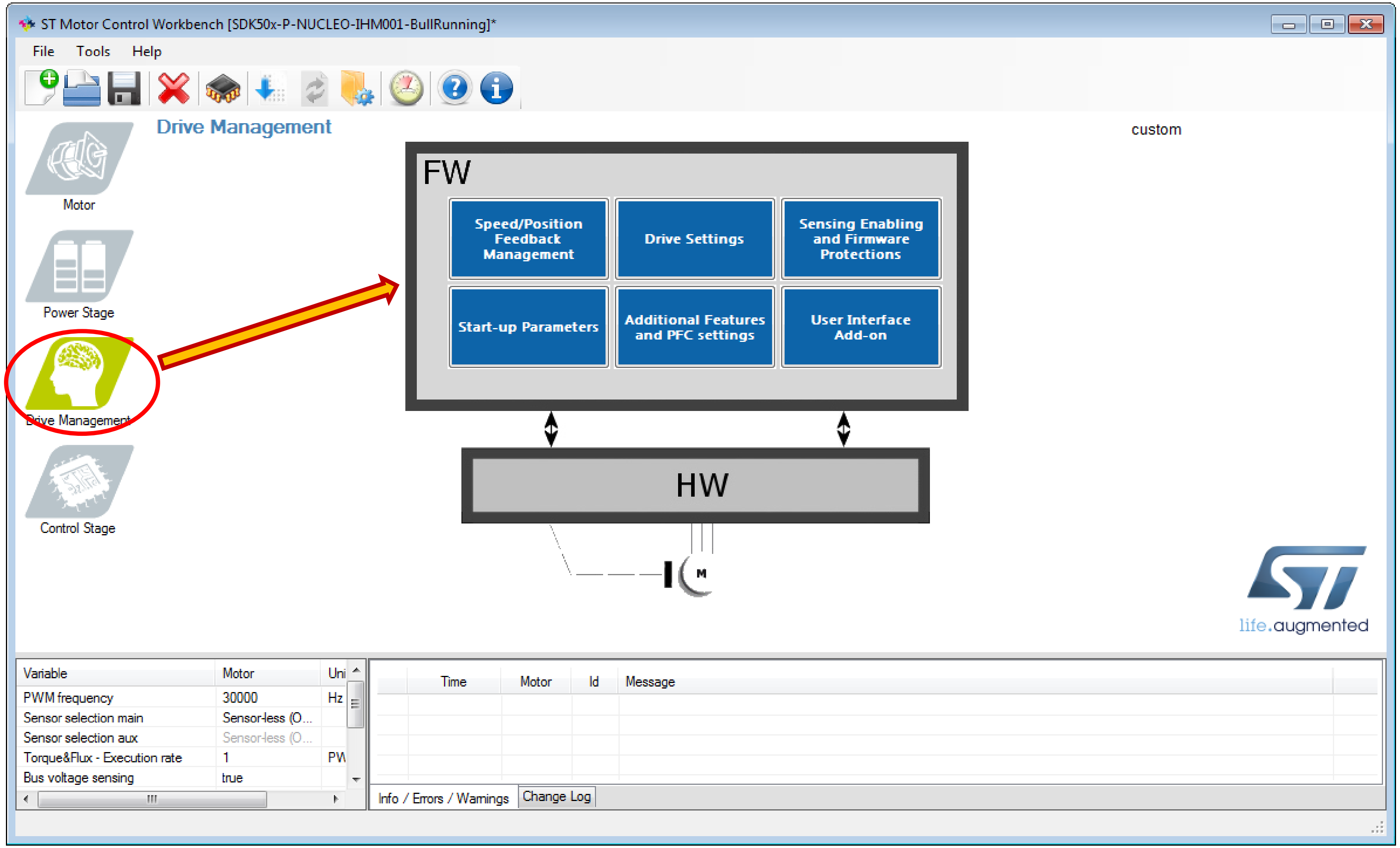
$$(1+R5/R4)\cdot\frac{(R2 // R3)}{((R2 // R3)+R1)}$$





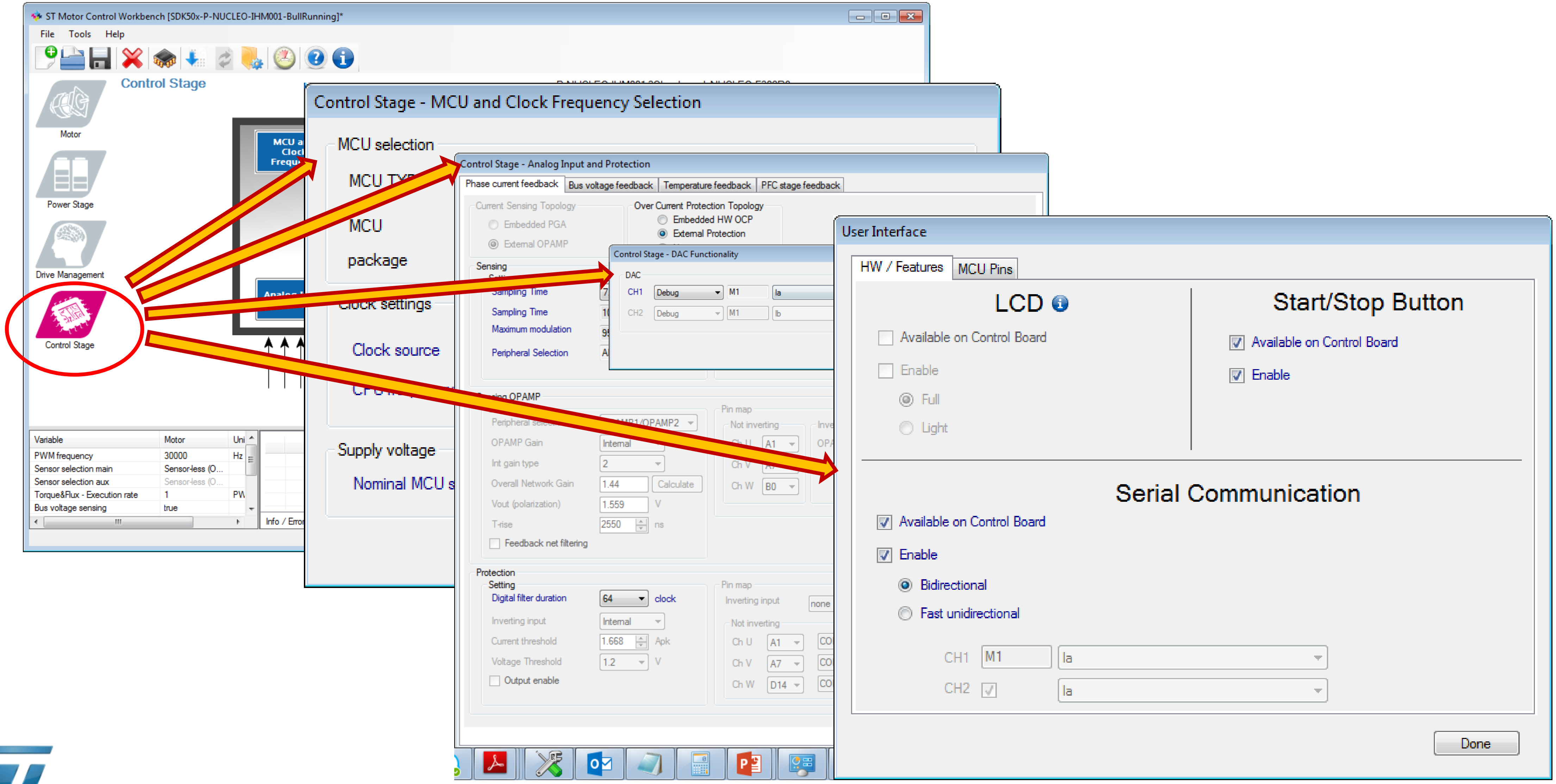


驱动控制管理



life.augmented

单片机相关



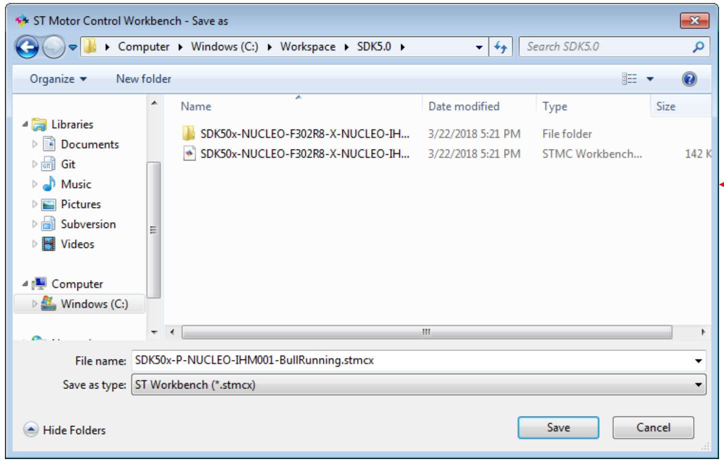
ST Motor Control Workbench [SDK50x-P-NUCLEO-IHM001-BullRunning]*
File Tools Help
Control Stage
Motor
Power Stage
Drive Management
Control Stage
Variable
Motor
PWM frequency
30000
Sensor selection main
Sensor selection aux
Torque&Flux - Execution rate
Bus voltage sensing
true
Control Stage - MCU and Clock Frequency Selection
MCU selection
MCU
package
Clock source
Supply voltage
Control Stage - Analog Input and Protection
Phase current feedback
Bus voltage feedback
Temperature feedback
PFC stage feedback
Current Sensing Topology
Embedded PGA
External OPAMP
Over Current Protection Topology
Embedded HW OCP
External Protection
Control Stage - DAC Functionality
DAC
CH1
Debug
M1
Ia
CH2
Ib
Sampling Time
Maximum modulation
Peripheral Selection
OPAMP Gain
Internal
Int gain type
Overall Network Gain
1.44
Calculate
Vout (polarization)
1.559
T-rise
2550
ns
Feedback net filtering
Pin map
Not inverting
Protection
Setting
Digital filter duration
64
clock
Inverting input
Current threshold
1.668
Apk
Voltage Threshold
1.2
Output enable
User Interface
HW / Features
MCU Pins
LCD
Available on Control Board
Enable
Full
Light
Start/Stop Button
Available on Control Board
Enable
Serial Communication
Available on Control Board
Enable
Bidirectional
Fast unidirectional
CH1
M1
Ia
CH2
Ia
Done

MC工程的生成

所有的参数配置完成后，点击生成图标，可根据所选的IDE生成MC应用工程：

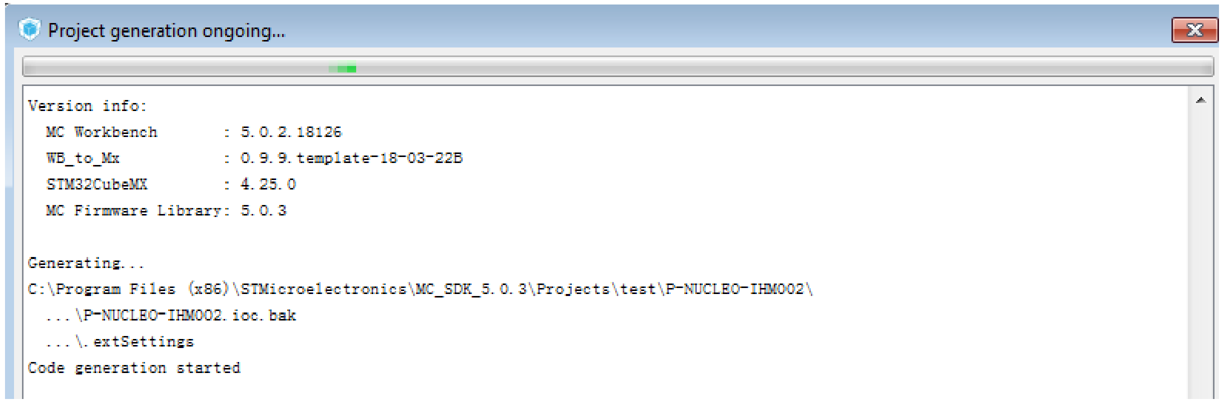
- 用户不再需要将MC Workbench输出文件拷贝到其工程下。
- STM32CubeMx作为接口被MC Workbench后台调用，来生成选择的IDE项目工作框架。

MC工程的生成



如果当前工程尚未保存，会显示一个文件管理器窗口，询问是否将当前工程设置保存为一个新项目。

如果当前工程已保存过，会显示一个进程窗口，告知用户脚本在执，同时更新用户信息表

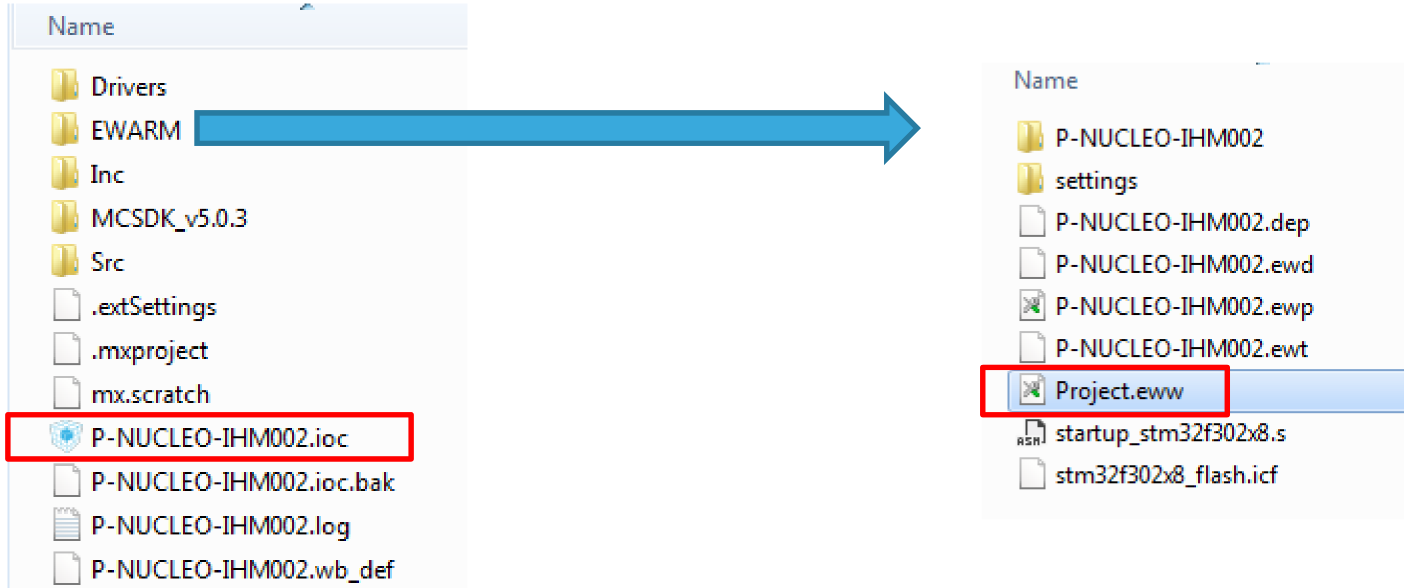


	Time	Motor	Id	Message
i	10:05:09			Project: 'P-NUCLEO-IHM002' saved successfully.
i	10:05:09			Generation files starting
i	10:05:09			Create the output folder C:\Program Files (x86)\STMicroelectronics\MC_SDK_5.0.3\Projects\test\P-NUCLEO-IHM002
i	10:05:38			Project files generated on folder:'C:\Program Files (x86)\STMicroelectronics\MC_SDK_5.0.3\Projects\test\P-NUCLEO-IHM0...

life.augmented

MC工程的生成

生成的IAR工程文件保存在如下路径：
$ProjectFolder\EWARM

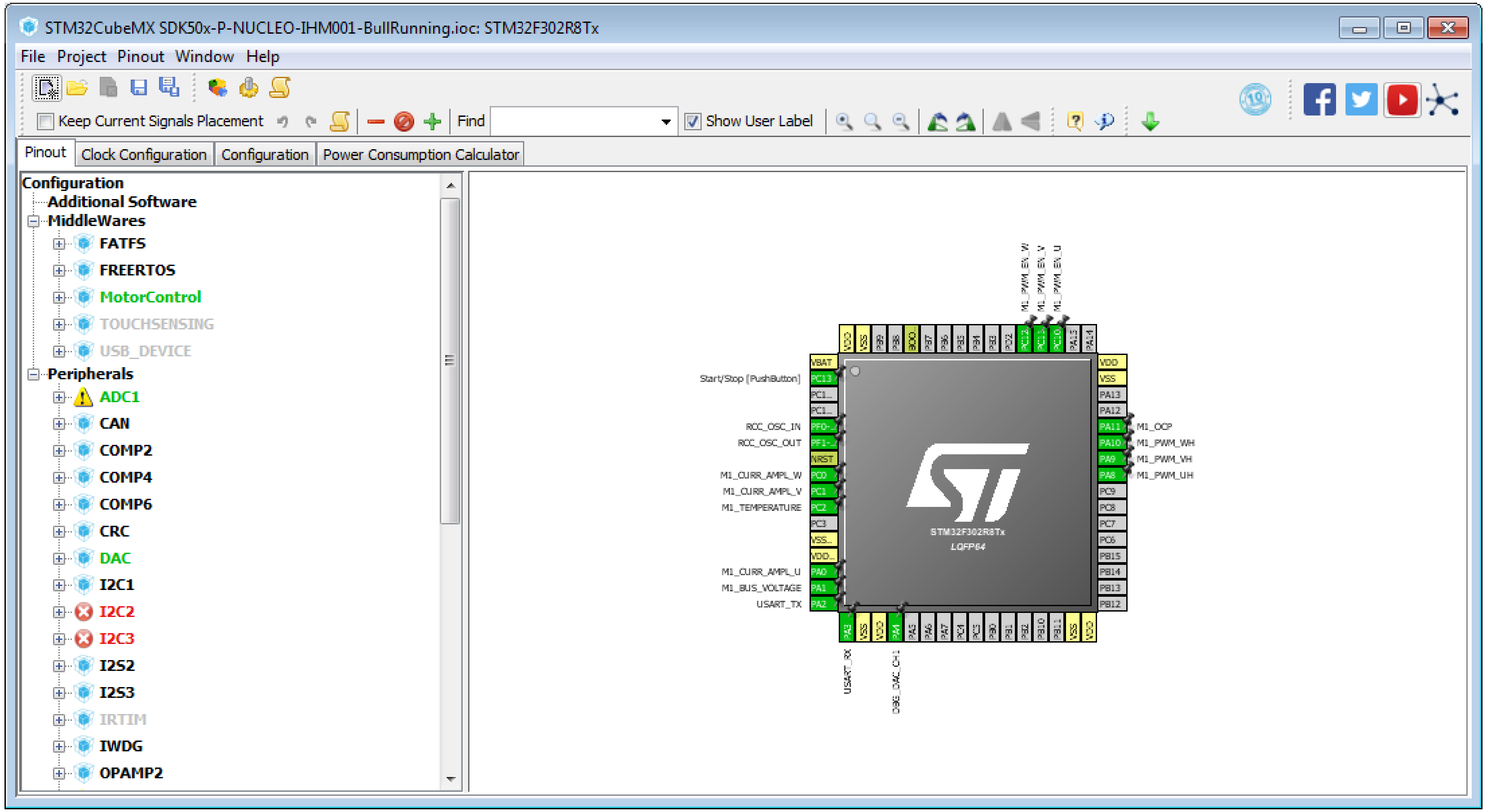


如果不需要配置其他外设，可直接打开.eww文件。

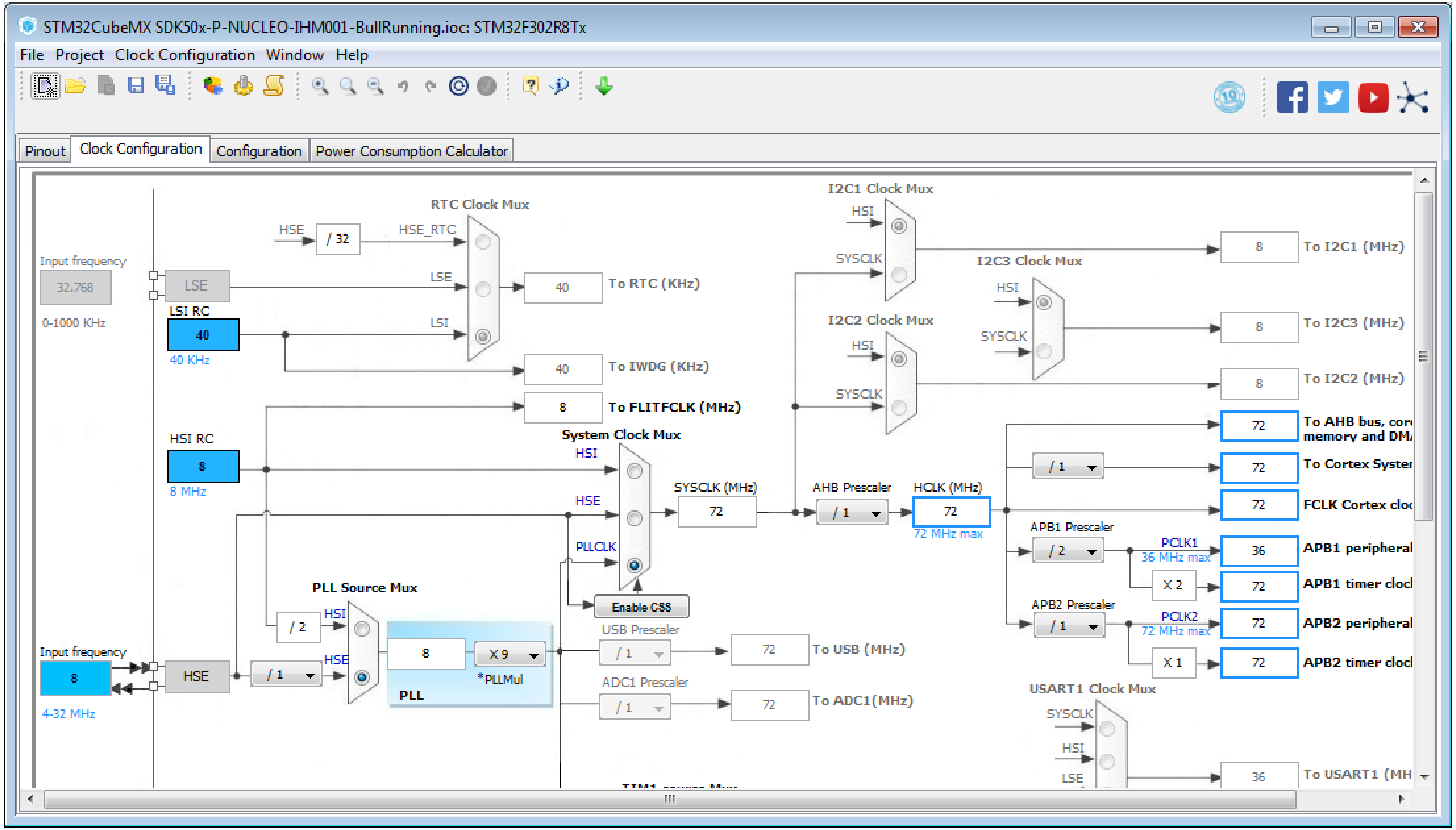
如果需要配置其他外设，请用CubeMX打开.ioc文件进行添加。
此操作最好在所有电机控制相关配置完成后进行，否则请在Workbentch中使用update ioc来更新ioc文件和FW参数(不包含硬件配置)

life.augmented

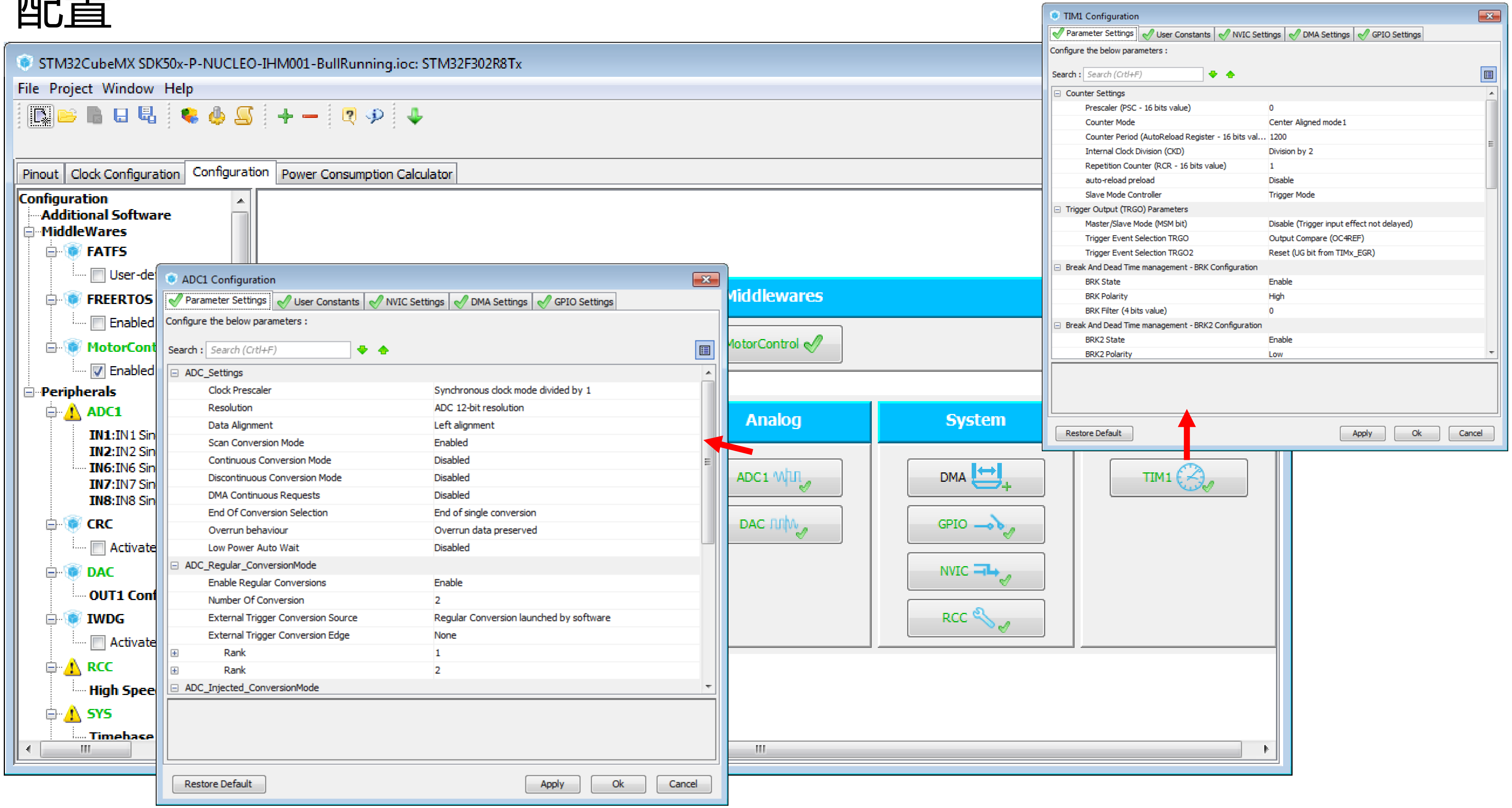
打开.ioc文件，STM32CubeMx将被打开。
图形化的引脚分配配置



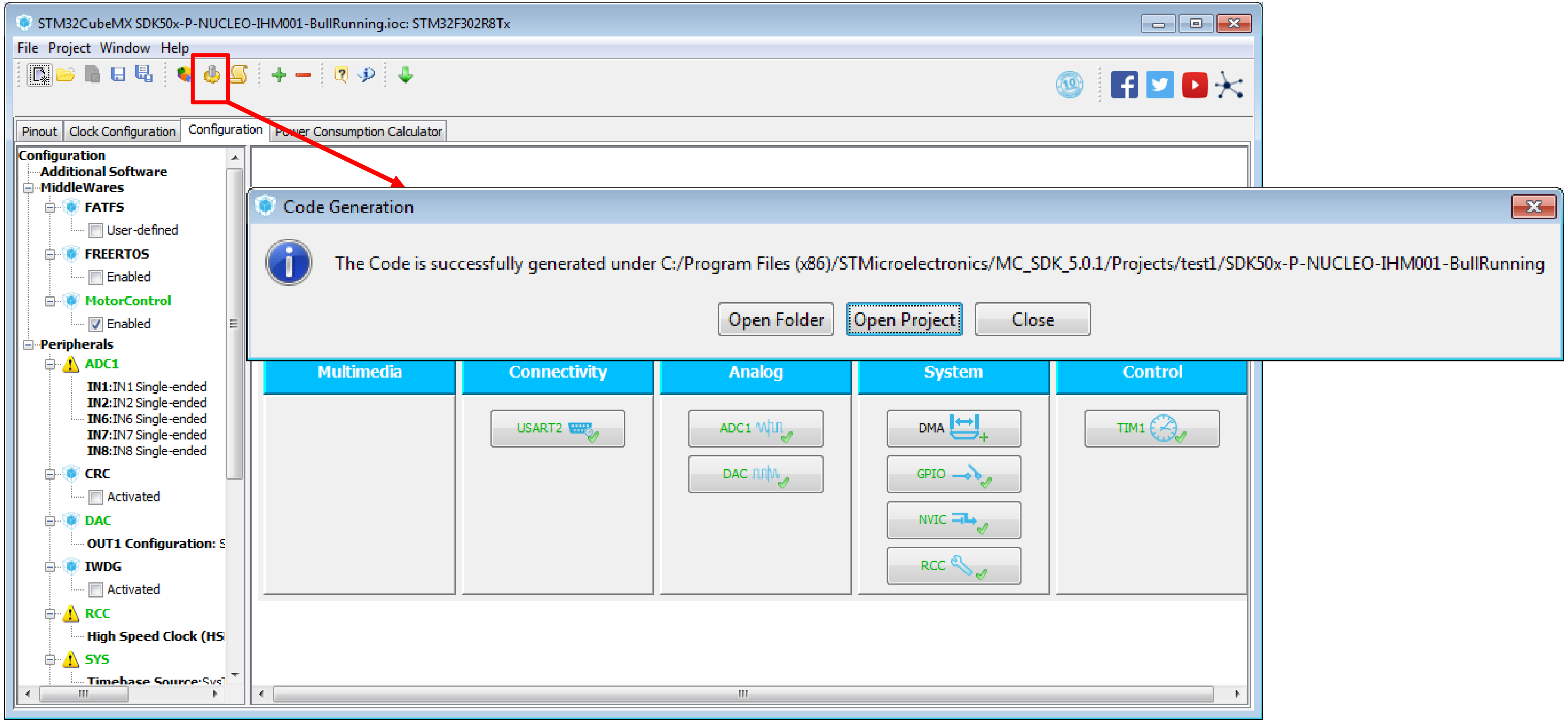
时钟树结构


STM32CubeMX SDK50x-P-NUCLEO-IHM001-BullRunning.ioc: STM32F302R8Tx
File Project Clock Configuration Window Help
Pinout
Clock Configuration
Configuration
Power Consumption Calculator
Input frequency
32.768
0-1000 KHz
LSE
LSI RC
40
40 KHz
HSI RC
8
8 MHz
Input frequency
8
4-32 MHz
HSE
RTC Clock Mux
HSE
/ 32
HSE_RTC
LSE
LSI
40
To RTC (KHz)
40
To IWDG (KHz)
8
To FLITFCLK (MHz)
System Clock Mux
HSI
HSE
PLLCLK
Enable CSS
SYSCLK (MHz)
72
AHB Prescaler
/ 1
HCLK (MHz)
72
72 MHz max
PLL Source Mux
HSI
/ 2
HSE
/ 1
8
X 9
*PLLMul
PLL
USB Prescaler
/ 1
72
To USB (MHz)
ADC1 Prescaler
/ 1
72
To ADC1(MHz)
I2C1 Clock Mux
HSI
SYSCLK
8
To I2C1 (MHz)
I2C3 Clock Mux
HSI
SYSCLK
8
To I2C3 (MHz)
I2C2 Clock Mux
HSI
SYSCLK
8
To I2C2 (MHz)
72
To AHB bus, core, memory and DMA
/ 1
72
To Cortex System
72
FCLK Cortex clock
APB1 Prescaler
/ 2
PCLK1
36 MHz max
36
APB1 peripheral
X 2
72
APB1 timer clock
APB2 Prescaler
/ 1
PCLK2
72 MHz max
72
APB2 peripheral
X 1
72
APB2 timer clock
USART1 Clock Mux
SYSCLK
HSI
LSE
36
To USART1 (MHz)

配置


STM32CubeMX SDK50x-P-NUCLEO-IHM001-BullRunning.ioc: STM32F302R8Tx
File Project Window Help
Pinout
Clock Configuration
Configuration
Power Consumption Calculator
ADC1 Configuration
Parameter Settings
User Constants
NVIC Settings
DMA Settings
GPIO Settings
Configure the below parameters :
ADC_Settings
Clock Prescaler Synchronous clock mode divided by 1
Resolution ADC 12-bit resolution
Data Alignment Left alignment
Scan Conversion Mode Enabled
Continuous Conversion Mode Disabled
Discontinuous Conversion Mode Disabled
DMA Continuous Requests Disabled
End Of Conversion Selection End of single conversion
Overrun behaviour Overrun data preserved
Low Power Auto Wait Disabled
ADC_Regular_ConversionMode
Enable Regular Conversions Enable
Number Of Conversion 2
External Trigger Conversion Source Regular Conversion launched by software
External Trigger Conversion Edge None
Rank 1
Rank 2
ADC_Injected_ConversionMode
Restore Default
Apply
Ok
Cancel
TIM1 Configuration
Counter Settings
Prescaler (PSC - 16 bits value) 0
Counter Mode Center Aligned mode1
Counter Period (AutoReload Register - 16 bits val... 1200
Internal Clock Division (CKD) Division by 2
Repetition Counter (RCR - 16 bits value) 1
auto-reload preload Disable
Slave Mode Controller Trigger Mode
Trigger Output (TRGO) Parameters
Master/Slave Mode (MSM bit) Disable (Trigger input effect not delayed)
Trigger Event Selection TRGO Output Compare (OC4REF)
Trigger Event Selection TRGO2 Reset (UG bit from TIMx_EGR)
Break And Dead Time management - BRK Configuration
BRK State Enable
BRK Polarity High
BRK Filter (4 bits value) 0
Break And Dead Time management - BRK2 Configuration
BRK2 State Enable
BRK2 Polarity Low
Middlewares
MotorControl
Analog
System
ADC1
DAC
DMA
GPIO
NVIC
RCC
TIM1
Configuration
Additional Software
MiddleWares
FATFS
FREERTOS
Enabled
MotorCont
Peripherals
ADC1
IN1:IN1 Sin
IN2:IN2 Sin
IN6:IN6 Sin
IN7:IN7 Sin
IN8:IN8 Sin
CRC
Activate
DAC
OUT1 Conf
IWDG
RCC
High Spee
SYS
Timebase

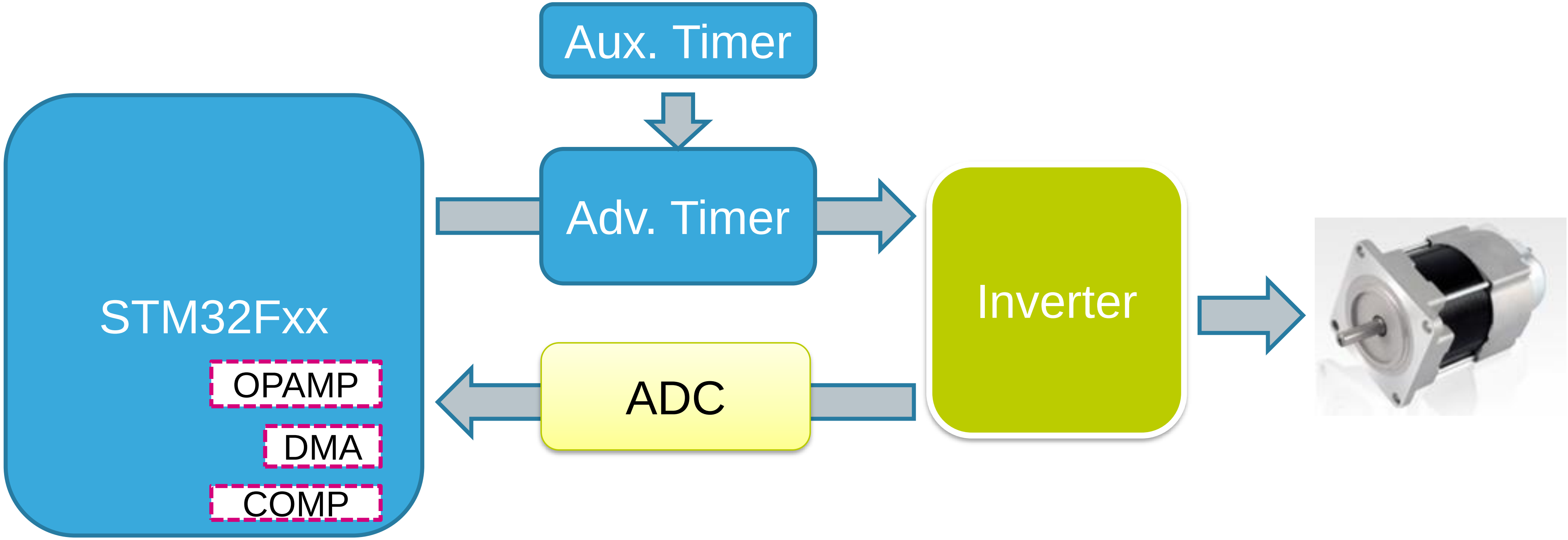
代码生成：



life.augmented

Motor Control 相关外设

在CubeMx中请不要修改电机控制相关外设的设定!



Motor Control 相关外设

三电阻电流采样所用资源

MCU	Single/Dual	Adv.Timer	DMA	ADC	Note
F0	Single	TIM1	DMA1_CH1	ADC1	The dual drive mode and the internal PGA are not available
F3	Single	TIM1	None	ADC1	Using one ADC
F3	Single/Dual	TIM1(TIM8)	None	ADC1 ADC2	Using two ADC
F3	Single/Dual	TIM1(TIM8)	None	ADC1 ADC2 (ADC3 ADC4)	Using four ADC
F4	Single/Dual	TIM1 (TIM8)	-	ADC1 ADC2	Using two ADC, ADC is used in time sharing.

life.augmented

单电阻采样所用资源(1)

MCU	Single/Dual	Adv. Timer	Aux. Timer	DMA	ADC	Note
F0	Single	TIM1	TIM3 (CH4)	DMA1_CH2 DMA1_CH3 DMA1_CH4	ADC1	F030x/F031x device configuration
F0	Single	TIM1	TIM15 (CH1)	DMA1_CH2 DMA1_CH5 DMA1_CH4	ADC1	F051x device configuration
F0	Single	TIM1	TIM15 (CH1)	DMA1_CH2 DMA1_CH5 DMA1_CH4	ADC1	F072x device configuration
F3	Single	TIM1	-	DMA1_CH4 DMA1_CH5	ADC1	-
F3	Dual	TIM1 TIM8	-	DMA1_CH4 DMA1_CH5 DMA2_CH1 DMA2_CH2	ADC1 ADC2	-

life.augmented

Motor Control 相关外设

单电阻采样所用资源(2)

MCU	Single/Dual	Adv. Timer	Aux. Timer	DMA	ADC	Note
F4	Single/Dual	TIM1	TIM5 (CH4)	DMA1,stream1,ch6; DMA2,stream4,ch6	ADC1	Option1:used by first motor when it is configured in single shunt, or by second motor when the first one isn’t in single shunt. ADC1 used for general purpose conversions
F4	Single/Dual	TIM8	TIM4 (CH2)	DMA1,stream3,ch2; DMA2,stream7,ch7	ADC1	Option1:used by second motor when it is configured in single shunt and when first motor isn’t in single shunt. ADC1 used for general purpose conversions
F4	Single/Dual	TIM8	TIM5 (CH4)	DMA1,stream1,ch6; DMA2,stream7,ch7	ADC3	Option2:used by first motor when it is configured in single shunt, or by second motor when the first one isn’t in single shunt. ADC1 used for general purpose conversions
F4	Single/Dual	TIM1	TIM4 (CH2)	DMA1,stream3,ch2; DMA2,stream4,ch6	ADC1	Option2:used by second motor when it is configured in single shunt and when first motor is also in single shunt. ADC1 used for general purpose conversions

F4xx用于单电机时，可在option 1和option 2间进行选择。

life.augmented

Motor Control 相关外设

ICS电流采样所用资源

MCU	Single/Dual	Advanced Timer	DMA	ADC	Note
F3	Single	TIM1 or TIM8	None	ADC1 ADC2	Used by the first or second motors depending on the user selection.
F3	Dual	TIM1 TIM8	None	ADC1 ADC2 ADC3 ADC4	-
F4	Single	TIM1 or TIM8	None	ADC1 ADC2	Used by the first or second motors depending on the user selection.
F4	Dual	TIM1 TIM8	None	ADC1 ADC2	-

life.augmented

ADC的配置

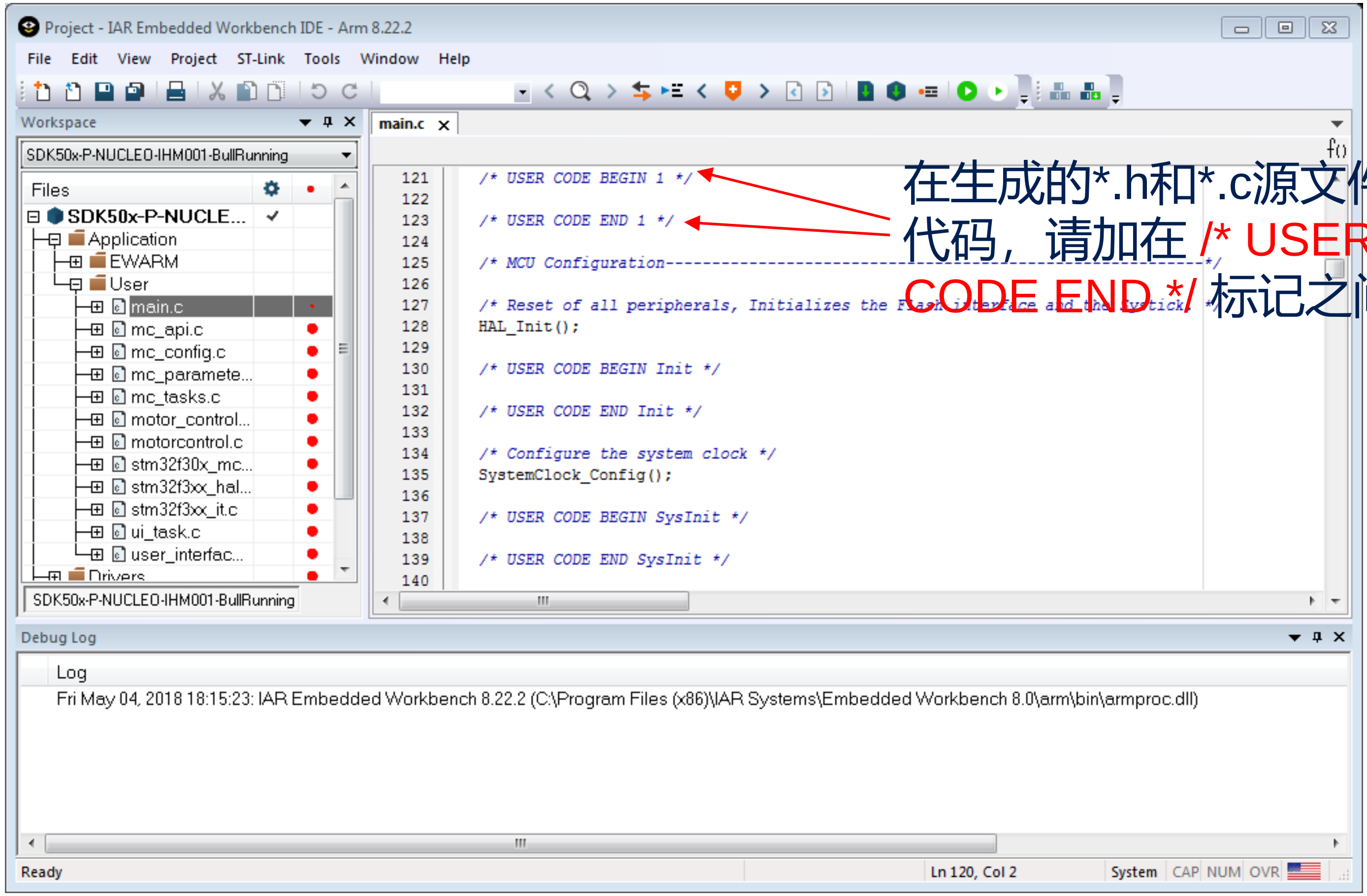
描述	下载地址
STM32F0模数转换模块（ADC）介绍	下载地址
STM32F1其余模块（包括ADC和计数器）介绍	下载地址
STM32F2模数转换模块（ADC）介绍	下载地址
STM32F3模数转换模块（ADC）介绍	下载地址
How to get the best ADC accuracy in STM32Fx Series and STM32L1 Series devices	下载地址
STM32™'s ADC modes and their applications	下载地址
Improving STM32F1x and STM32L1x ADC resolution by oversampling	下载地址
使用STM32F2xx 和STM32F4xx 微控制器时如何提高ADC 测量精度	下载地址
STM32F30x ADC modes and application	下载地址

Timer 的配置

描述	链接
STM32F0定时器模块（TIM）介绍	下载地址
STM32F1其余模块（包括ADC和计数器）介绍	下载地址
STM32F2定时器模块（TIM）介绍	下载地址
STM32F3通用定时器模块（TIM）介绍	下载地址
STM32F3定时器模块新增功能介绍	下载地址
General-purpose timer cookbook	下载地址
STM32F1xx、STM32F2xx、STM32F4xx、STM32L1xx、 STM32F30/31/37/38x 定时器概览	下载地址

life.augmented

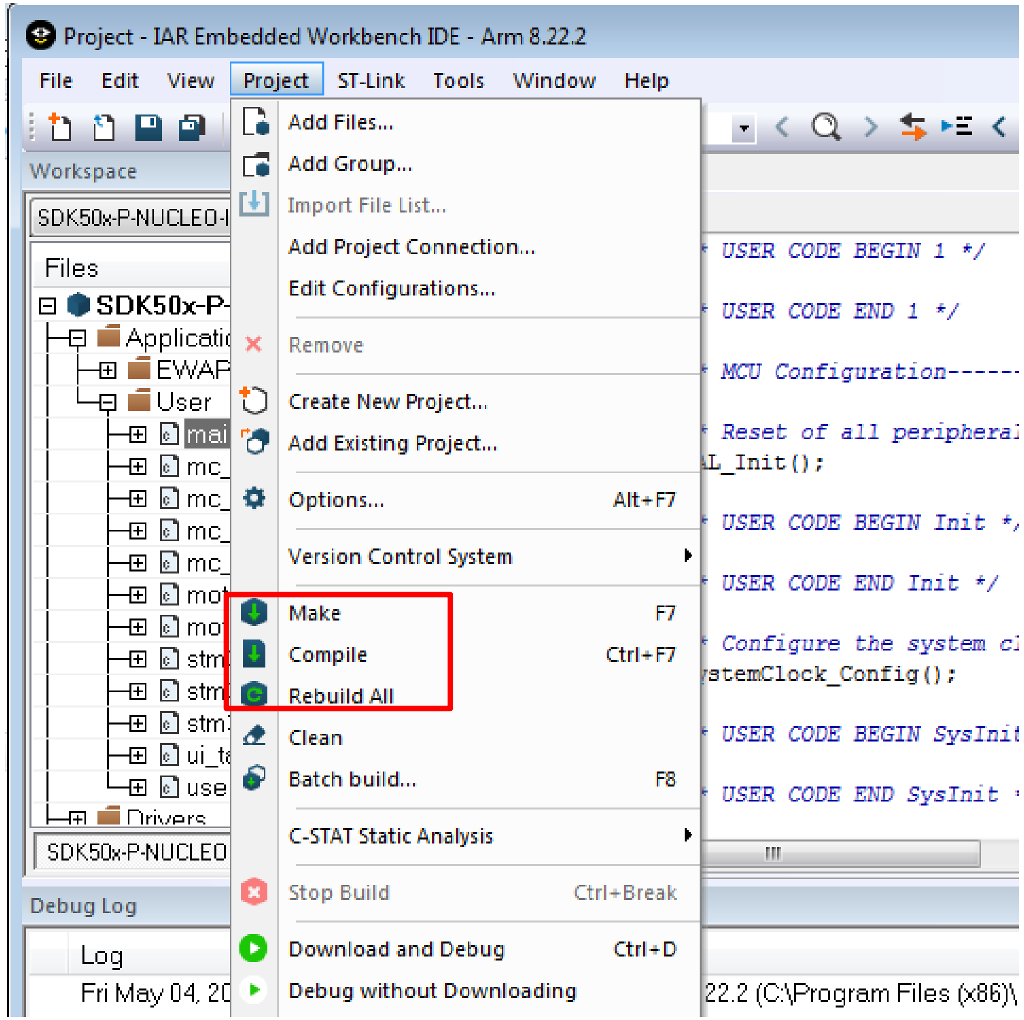
IAR Embedded Workbench for Arm (v8.xx)

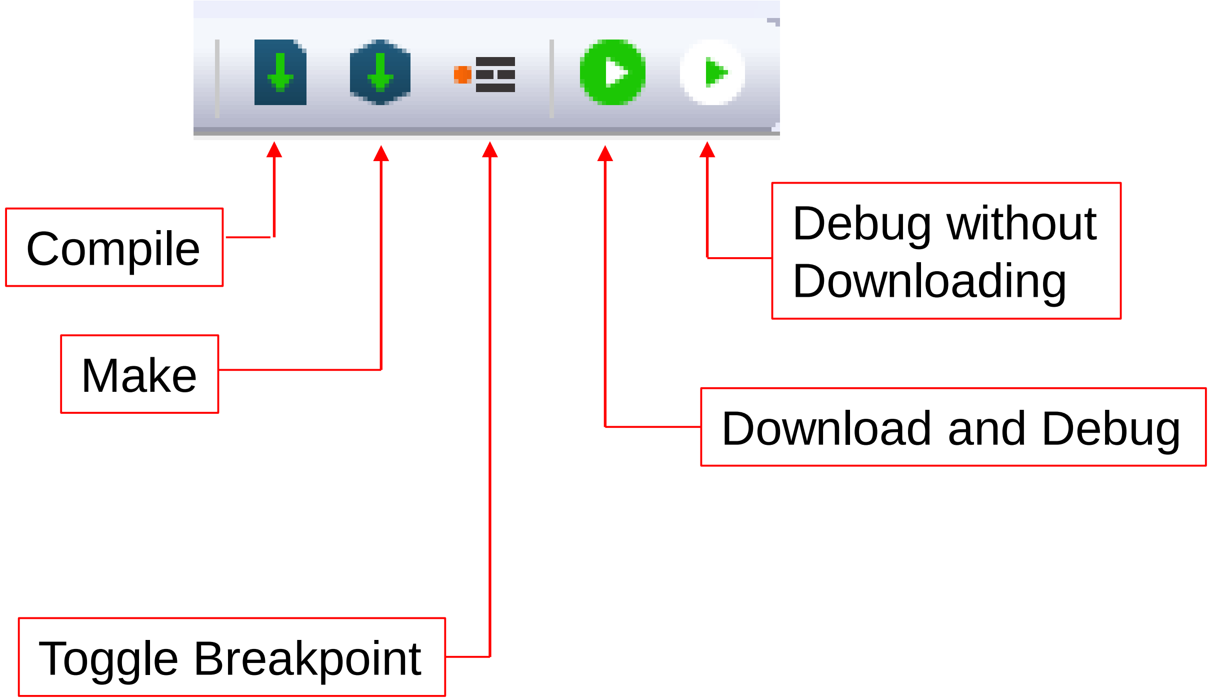


在生成的*.h和*.c源文件中，用户如果添加自己的应用代码，请加在 /* USER CODE BEGIN */和/* USER CODE END */ 标记之间。

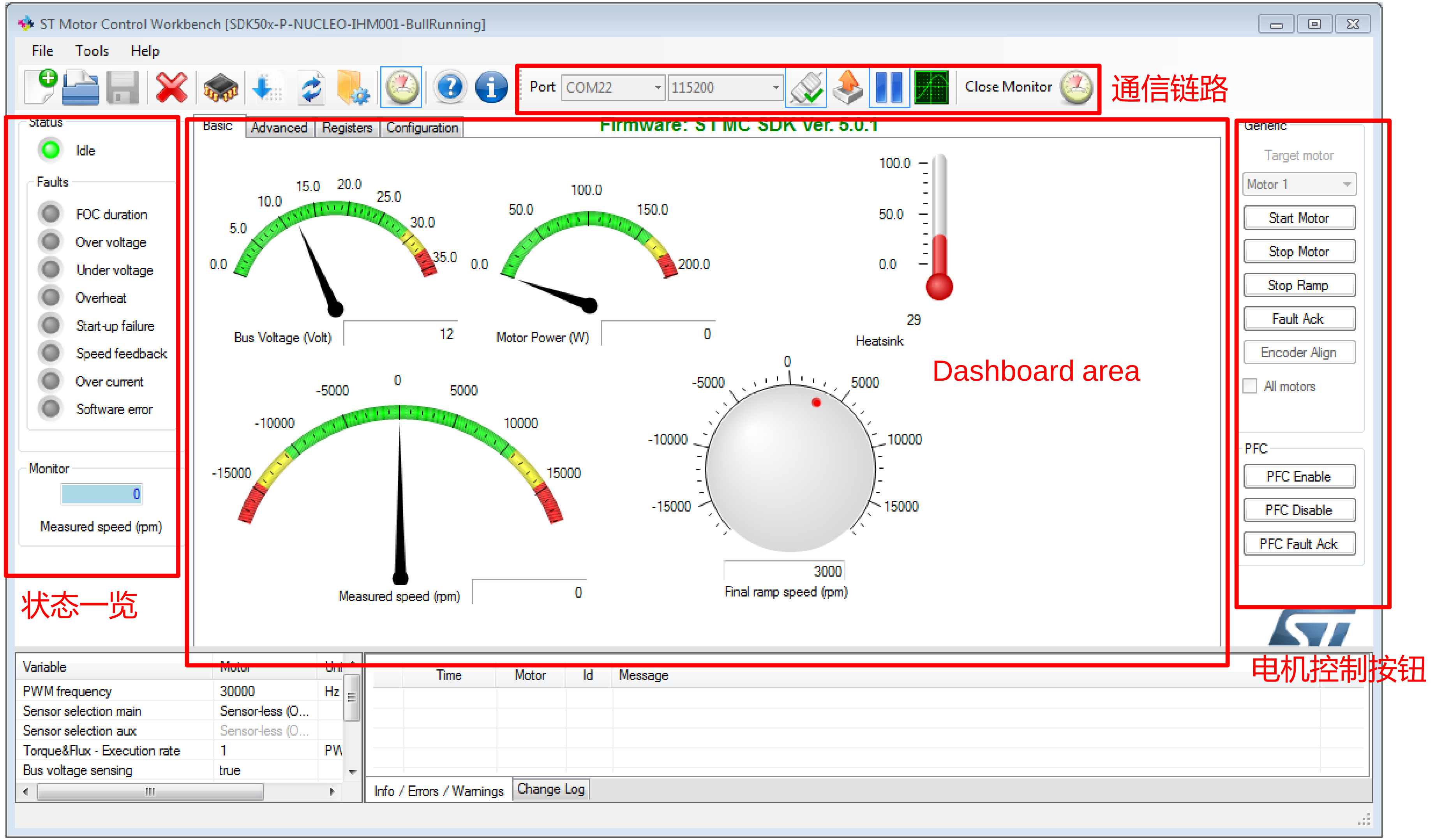
在IAR Embedded Workbench for Arm v8.xx中，C编译器的优化选择请设定为 ***Speed.***

MC 工程编译和下载


Project - IAR Embedded Workbench IDE - Arm 8.22.2
File Edit View Project ST-Link Tools Window Help
Workspace
Files
Add Files...
Add Group...
Import File List...
Add Project Connection...
Edit Configurations...
Remove
Create New Project...
Add Existing Project...
Options... Alt+F7
Version Control System
Make F7
Compile Ctrl+F7
Rebuild All
Clean
Batch build... F8
C-STAT Static Analysis
Stop Build Ctrl+Break
Download and Debug Ctrl+D
Debug without Downloading
Debug Log
Log

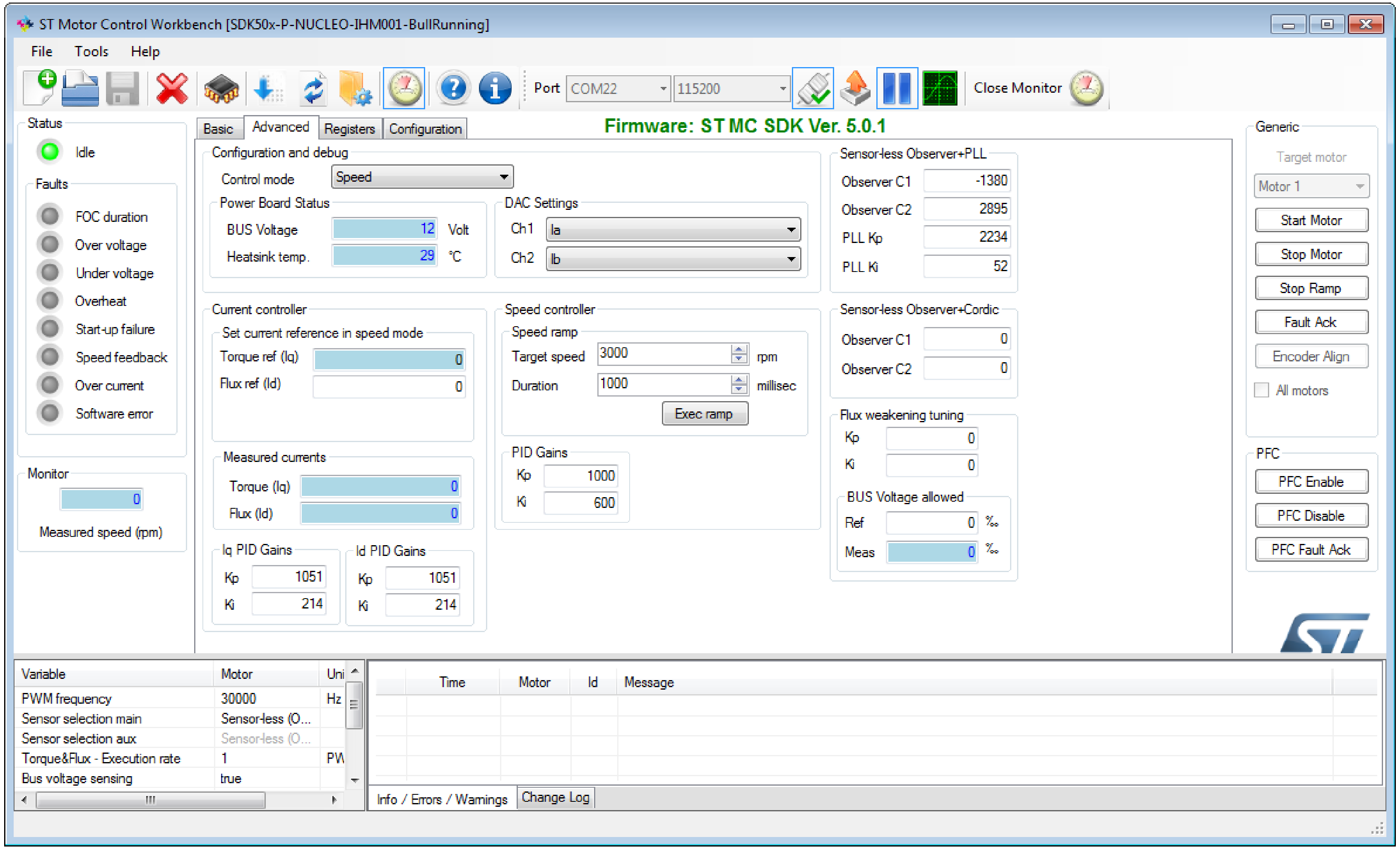

Compile
Make
Toggle Breakpoint
Download and Debug
Debug without Downloading

电机控制和监控



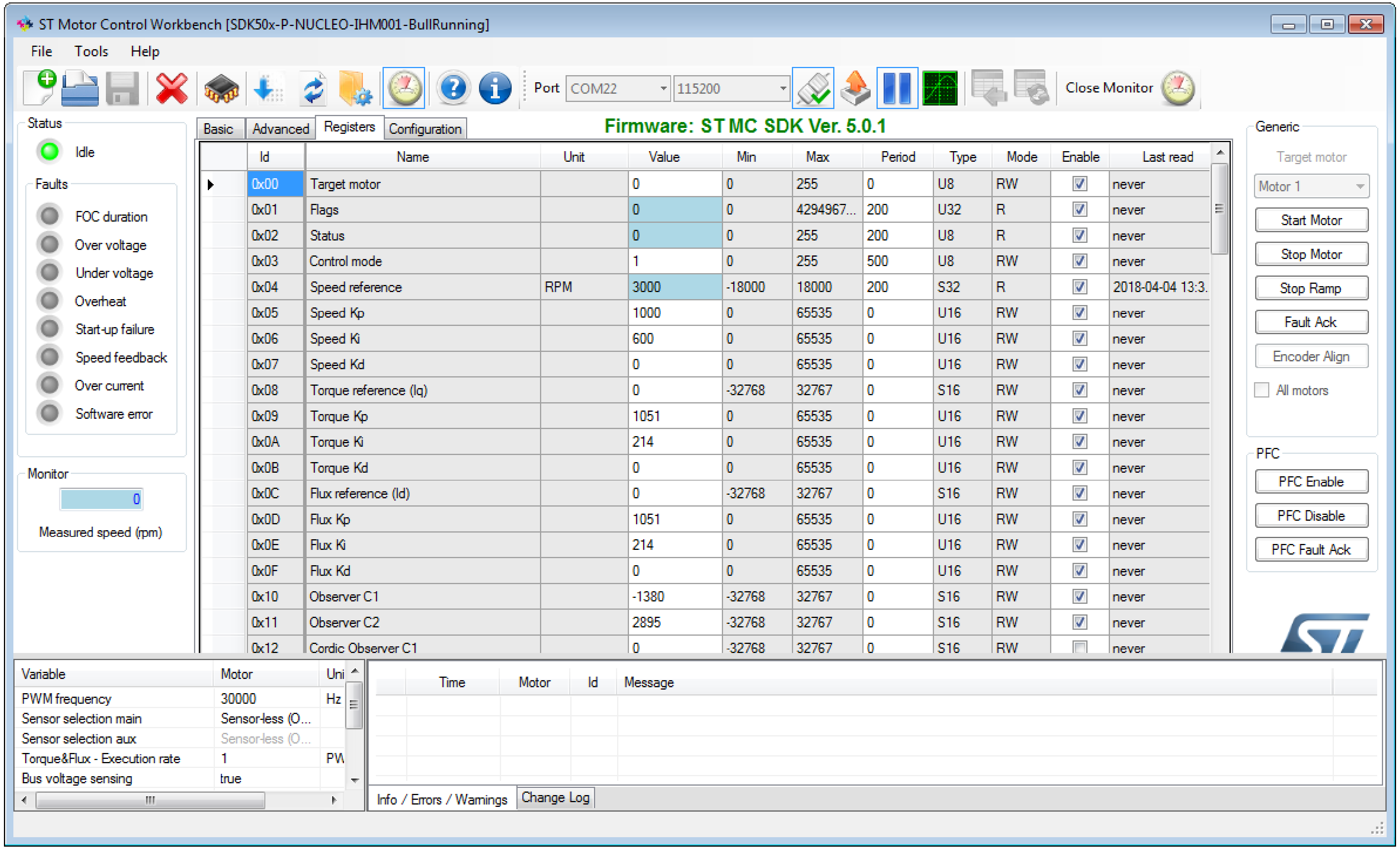
ST Motor Control Workbench [SDK50x-P-NUCLEO-IHM001-BullRunning]
File
Tools
Help
Port
COM22
115200
Close Monitor
通信链路
Status
Idle
Faults
FOC duration
Over voltage
Under voltage
Overheat
Start-up failure
Speed feedback
Over current
Software error
Monitor
0
Measured speed (rpm)
状态一览
Basic
Advanced
Registers
Configuration
Firmware: ST MC SDK Ver. 5.0.1
Bus Voltage (Volt)
12
Motor Power (W)
0
Heatsink
29
Dashboard area
Measured speed (rpm)
0
Final ramp speed (rpm)
3000
Generic
Target motor
Motor 1
Start Motor
Stop Motor
Stop Ramp
Fault Ack
Encoder Align
All motors
PFC
PFC Enable
PFC Disable
PFC Fault Ack
电机控制按钮
Variable
Motor
PWM frequency
30000
Hz
Sensor selection main
Sensor-less (O...
Sensor selection aux
Sensor-less (O...
Torque&Flux - Execution rate
1
Bus voltage sensing
true
Time
Motor
Id
Message
Info / Errors / Warnings
Change Log

电机控制和监控



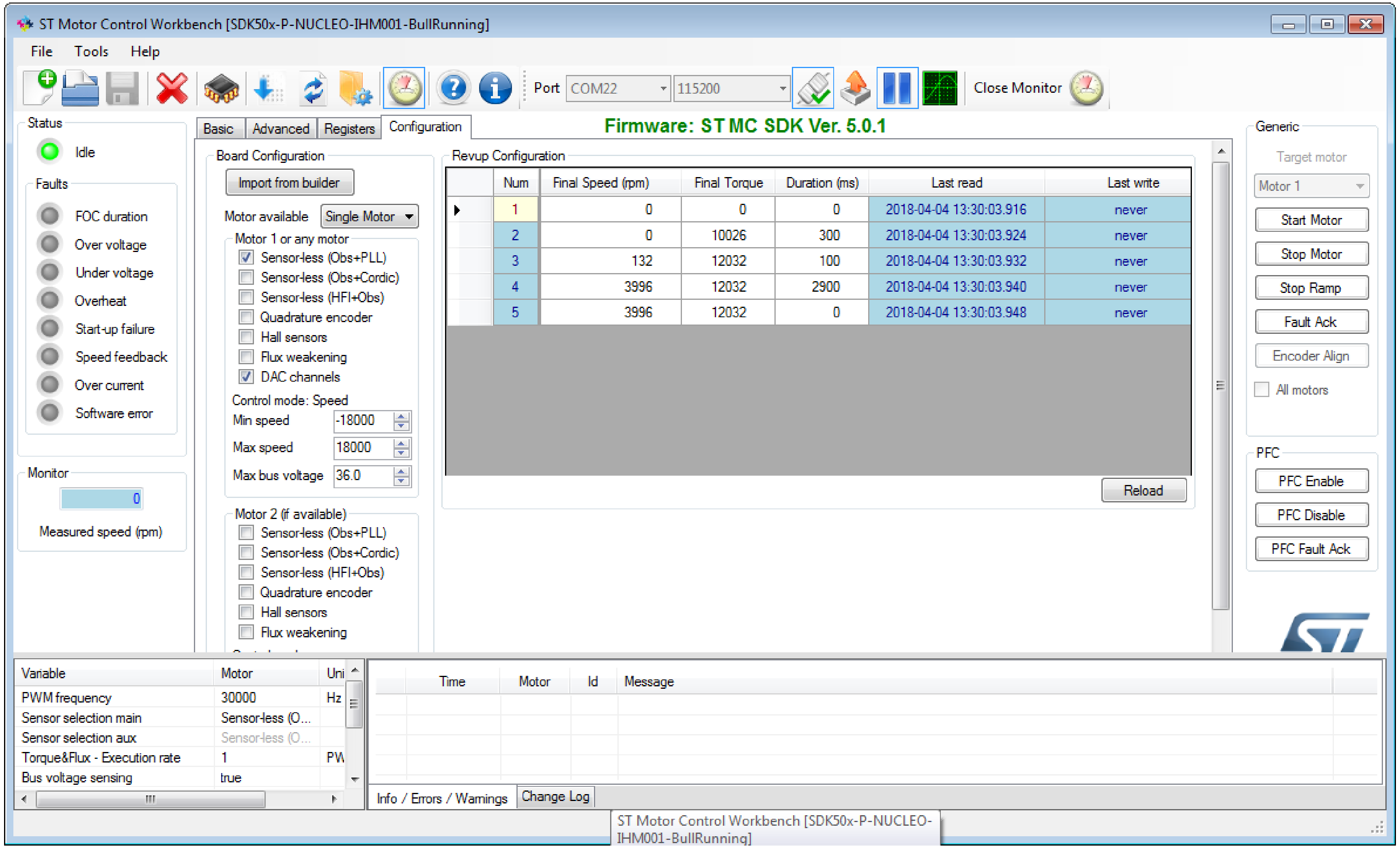
life.augmented

电机控制和监控



life.augmented

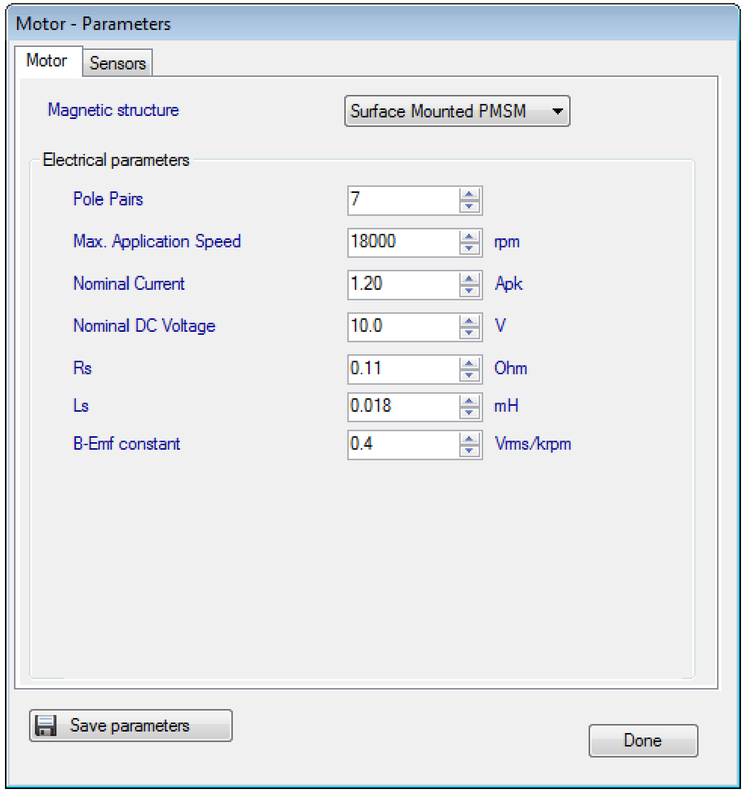
电机控制和监控

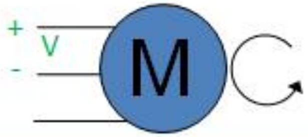


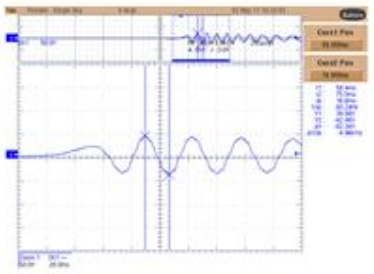
ST Motor Control Workbench [SDK50x-P-NUCLEO-IHM001-BullRunning]
File
Tools
Help
Port
COM22
115200
Close Monitor
Status
Idle
Faults
FOC duration
Over voltage
Under voltage
Overheat
Start-up failure
Speed feedback
Over current
Software error
Monitor
0
Measured speed (rpm)
Basic
Advanced
Registers
Configuration
Firmware: ST MC SDK Ver. 5.0.1
Board Configuration
Import from builder
Motor available
Single Motor
Motor 1 or any motor
Sensor-less (Obs+PLL)
Sensor-less (Obs+Cordic)
Sensor-less (HFI+Obs)
Quadrature encoder
Hall sensors
Flux weakening
DAC channels
Control mode: Speed
Min speed -18000
Max speed 18000
Max bus voltage 36.0
Motor 2 (if available)
Sensor-less (Obs+PLL)
Sensor-less (Obs+Cordic)
Sensor-less (HFI+Obs)
Quadrature encoder
Hall sensors
Flux weakening
Revup Configuration
Num | Final Speed (rpm) | Final Torque | Duration (ms) | Last read | Last write
1 | 0 | 0 | 0 | 2018-04-04 13:30:03.916 | never
2 | 0 | 10026 | 300 | 2018-04-04 13:30:03.924 | never
3 | 132 | 12032 | 100 | 2018-04-04 13:30:03.932 | never
4 | 3996 | 12032 | 2900 | 2018-04-04 13:30:03.940 | never
5 | 3996 | 12032 | 0 | 2018-04-04 13:30:03.948 | never
Reload
Generic
Target motor
Motor 1
Start Motor
Stop Motor
Stop Ramp
Fault Ack
Encoder Align
All motors
PFC
PFC Enable
PFC Disable
PFC Fault Ack
Variable | Motor | Uni
PWM frequency | 30000 | Hz
Sensor selection main | Sensor-less (O...
Sensor selection aux | Sensor-less (O...
Torque&Flux - Execution rate | 1 | PW
Bus voltage sensing | true
Time | Motor | Id | Message
Info / Errors / Warnings
Change Log
ST Motor Control Workbench [SDK50x-P-NUCLEO-IHM001-BullRunning]

Workbench关键配置参数说明

- 马达参数配置
  - 极对数
  - 最大转速
  - 最大电流
  - 供电电压
  - 电机电阻
  - 电机电感
  - 电机反电势常数

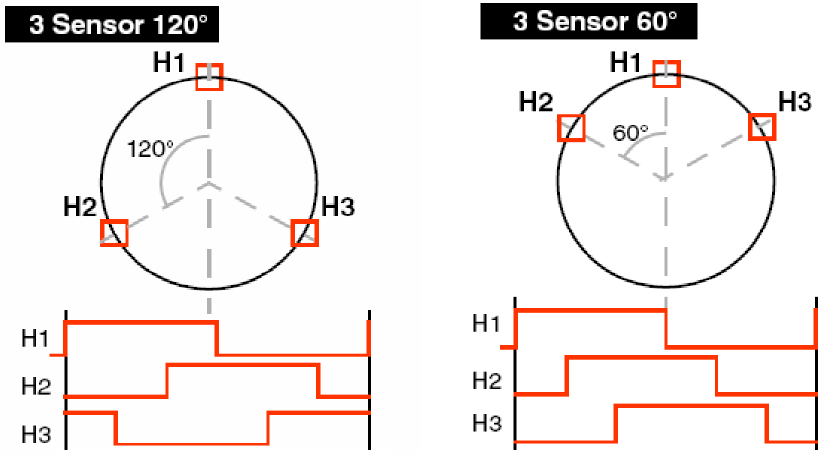


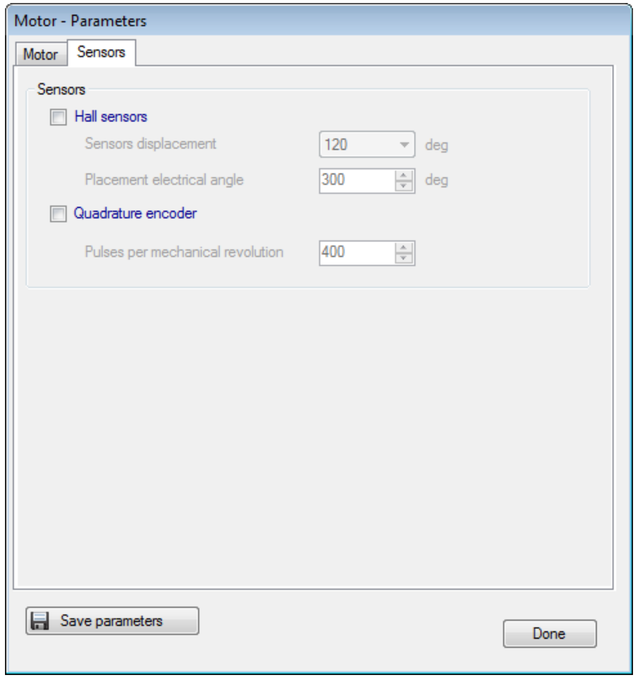




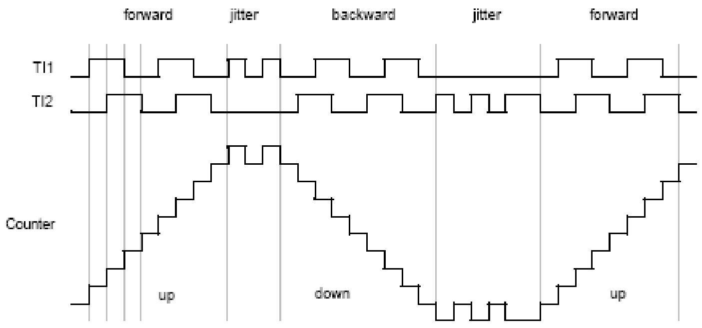
Workbench 关键配置参数说明

- Hall同步电角度：
  - 电机Hall A的上升沿到电机A相反电动势最高点的延迟角度。
  - 默认电机A相的反电动势最高点作为电角度的0度；

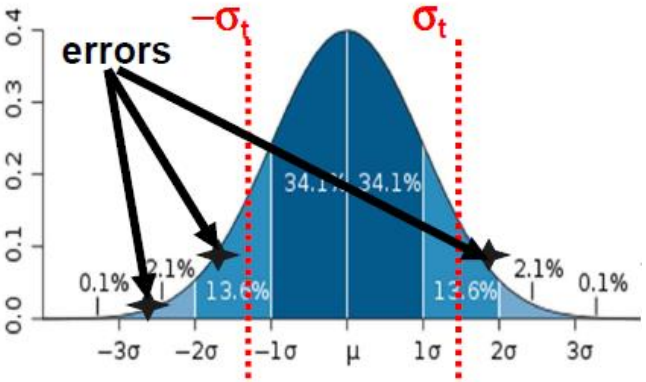




- 编码器参数
  - Resolution更清晰，分辨率，单位：Pulse/Round
  - 旋转一圈的编码器脉冲个数



Workbench 关键配置参数说明



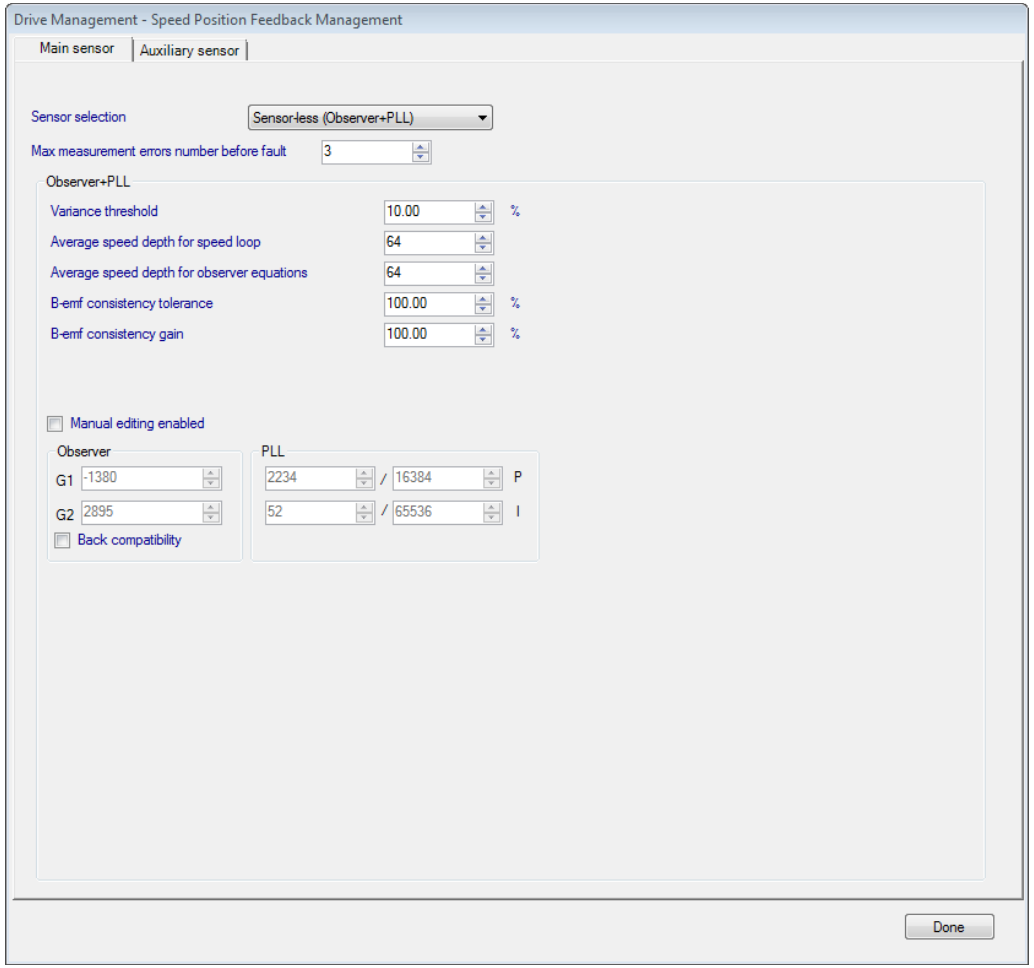
$\sigma_\tau = \mu^2$ * 'variance threshold'

Speed Average value

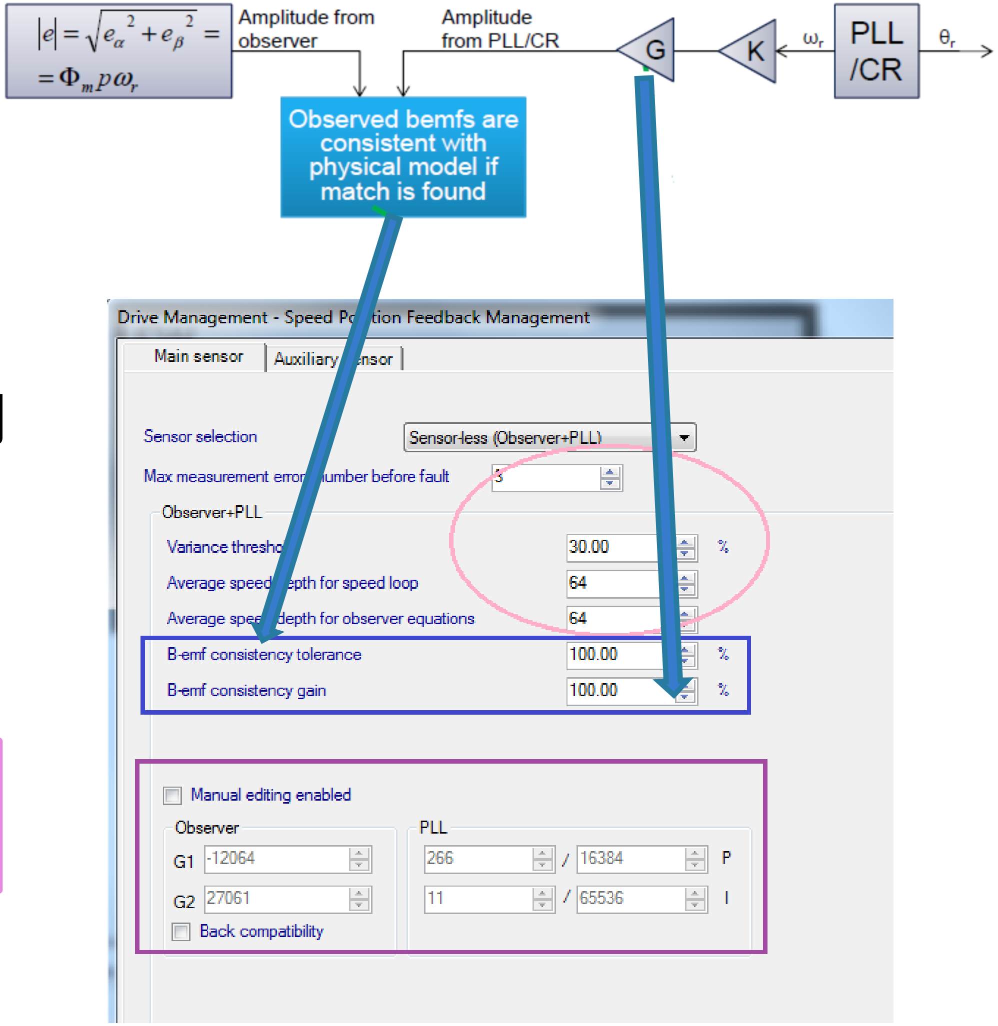
$$\mu = \frac{\sum_{i=1}^{64} \omega_i}{64}$$

Speed Variance

$$\sigma^2 = \frac{\sum_{i=1}^{64} (\omega_i - \mu)^2}{64}$$



Workbench 关键配置参数说明



$$|e| = \sqrt{e_\alpha^2 + e_\beta^2} = \Phi_m p \omega_r$$

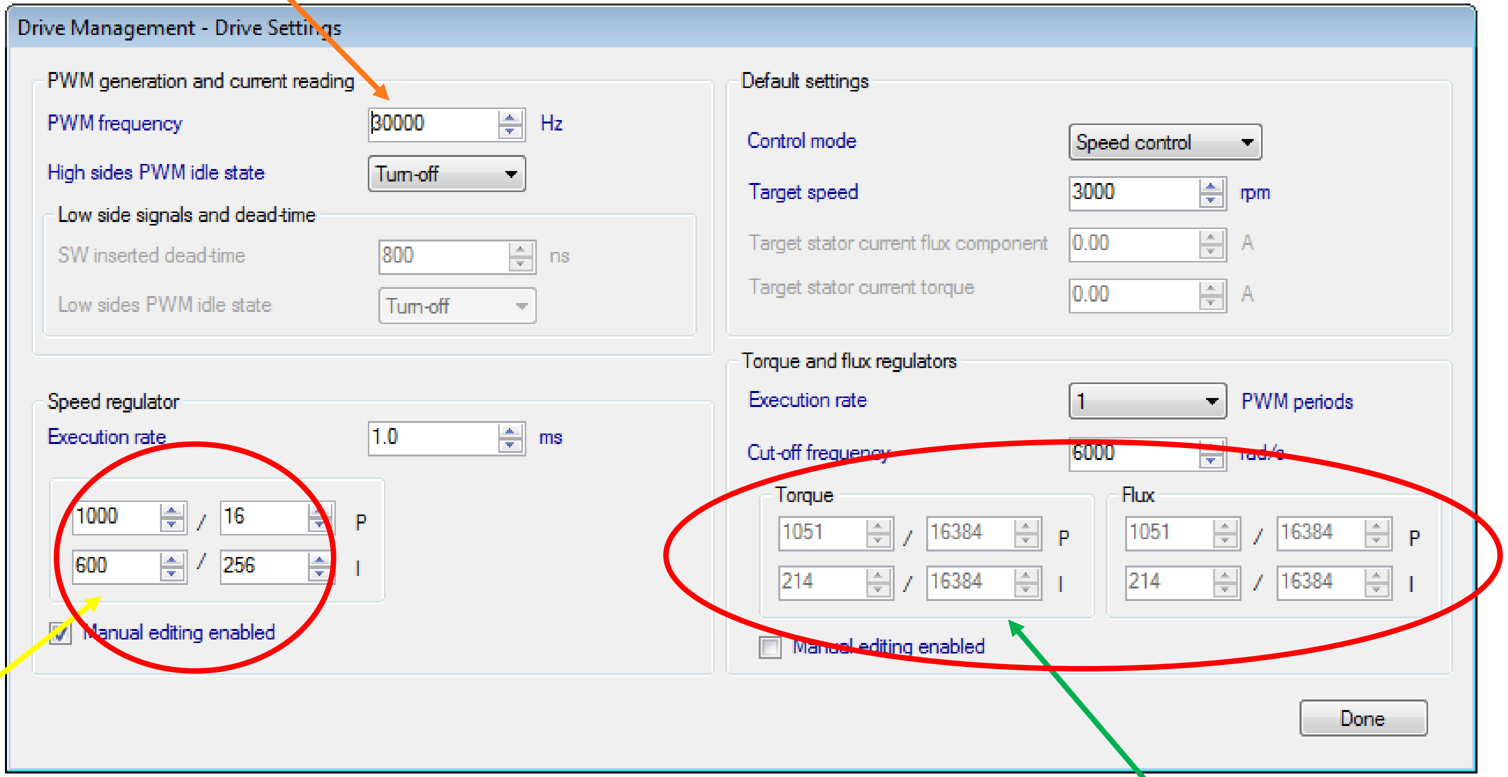
➢ BEMF收敛：

- 一般用于堵转判断
- 设定为100%时，忽略此判断

根据参数计算得到的系数，一般情况下无需修改，保持为默认数据

Workbench 关键配置参数说明

PWM载波频率



速度环Kp & Ki

电流环Kp & Ki

life.augmented

Workbench 关键配置参数说明

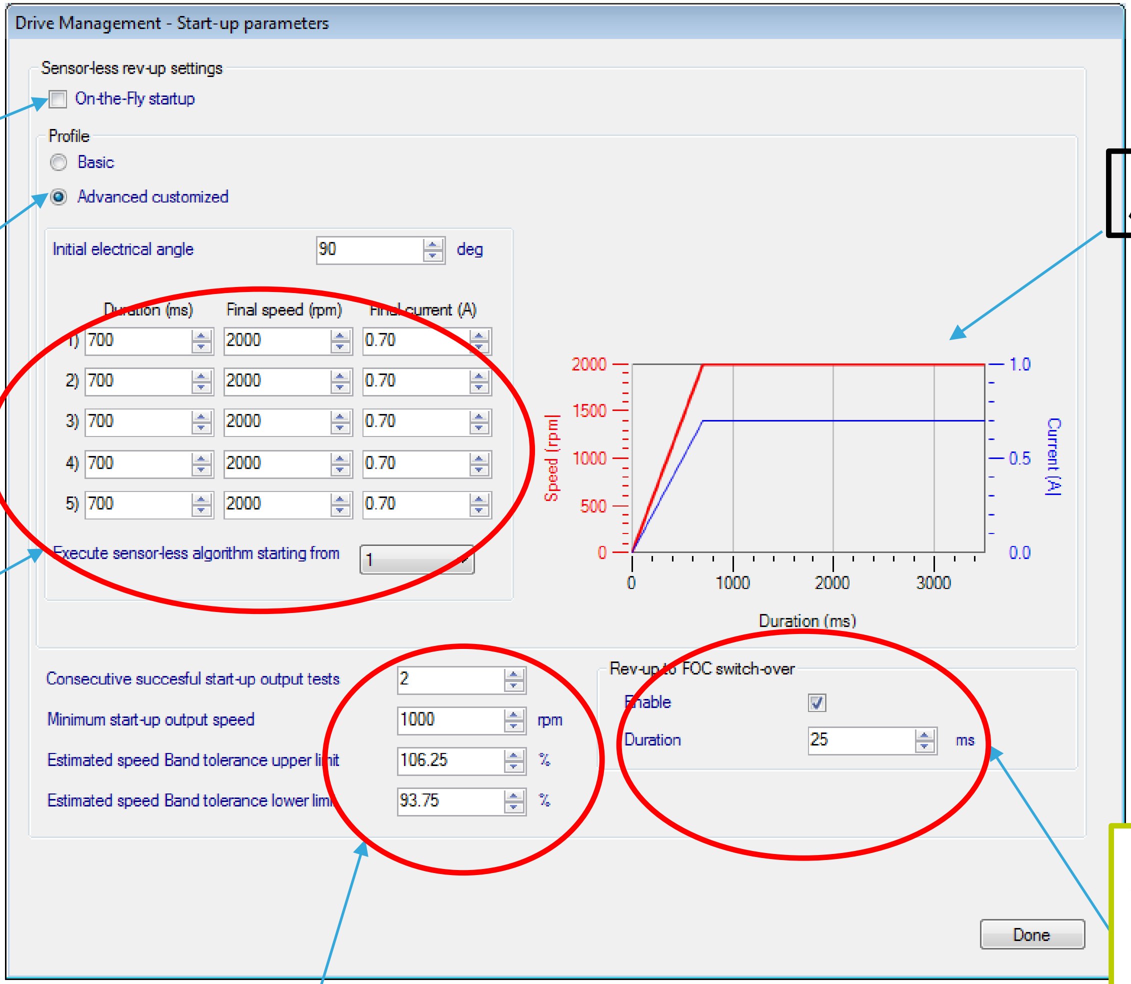
➢ 配置无传感器开环启动参数

- 有传感器不用配置

顺逆风启动检测使能

折线或曲线启动选择

启动曲线配置，包含速度，电流，时间



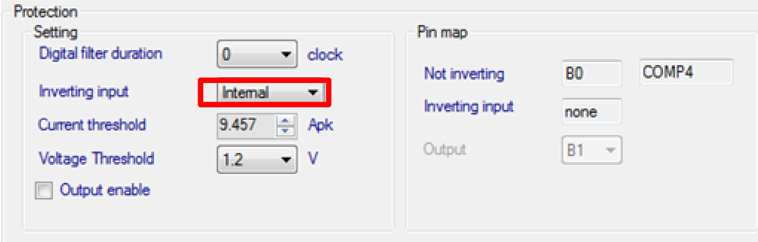
启动曲线

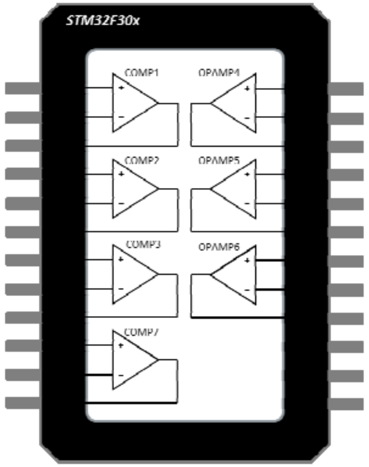
启动-FOC过渡期设定

切入闭环条件判定

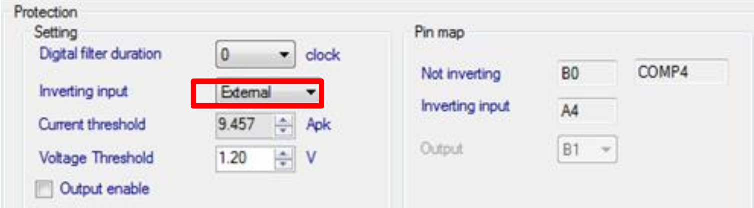
COMP 的配置

- 3 种方式设定OCP的过流阈值
  - 内部参考值，省一个管脚，但是该值较粗（只有有限的几个值可选）

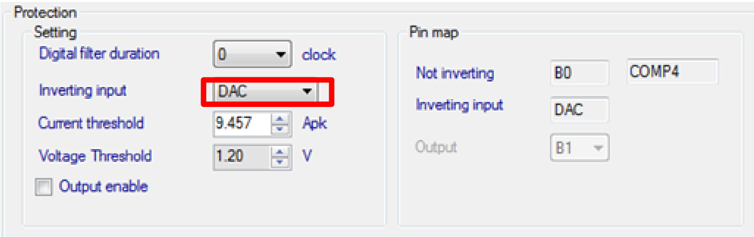




  - 外部参考值，需要一个管脚（PA4），但是该值容易调整

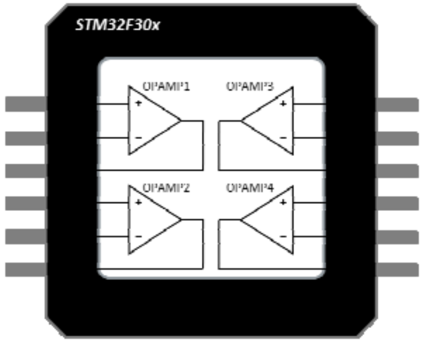


  - DAC通道，需要一个管脚（DAC窗口定义），该值容易调整



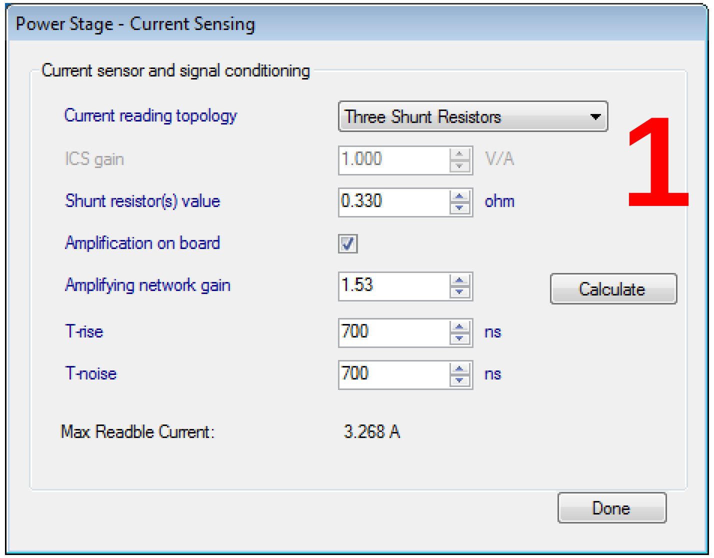
life.augmented

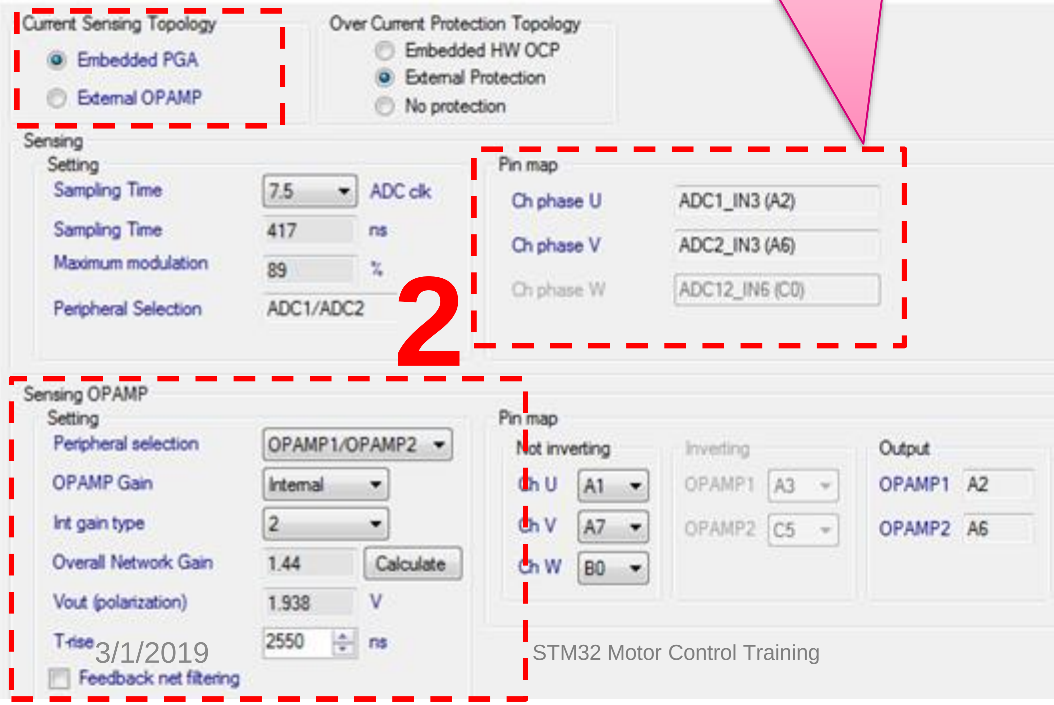
内置高速运放的配置



MCU	Configuration	or
STM32F303	OPAMP1+ADC1 OPAMP2+ADC2	OPAMP3+ADC3 OPAMP4+ADC4
STM32F302	OPAMP1+ADC1 OPAMP2+ADC2	

不能选择ADC的引脚，因为是和OPAMP共用同一个引脚



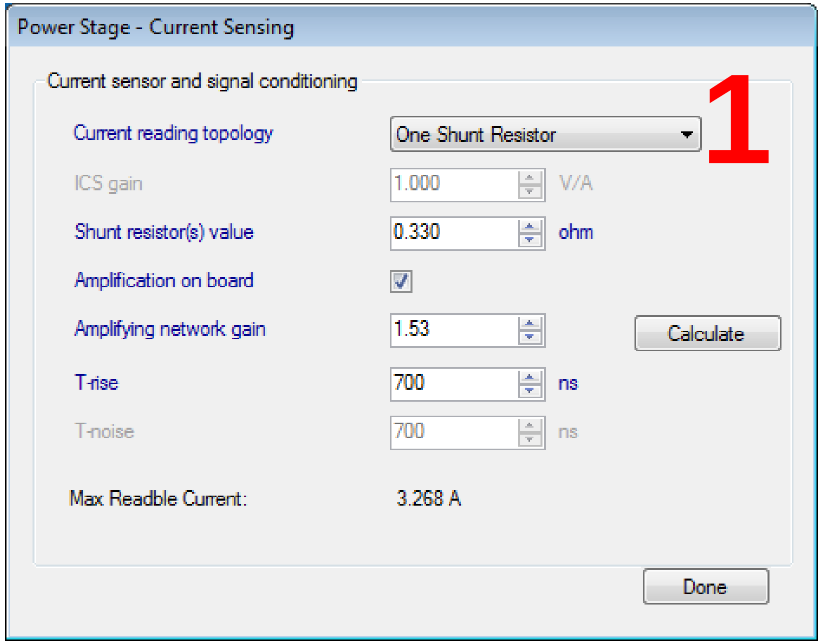


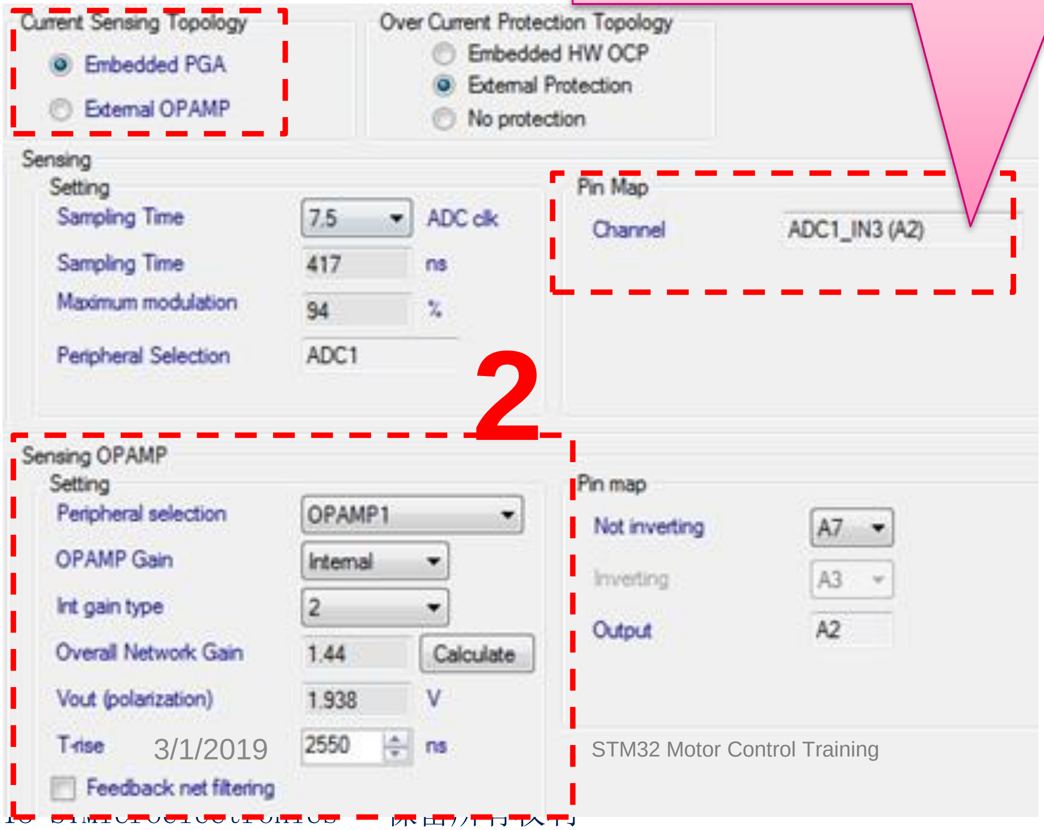
life.augmented

内置高速运放的配置

MCU	Configuration	or	or	or
STM32F303	OPAMP1+ADC1	OPAMP2+ADC2	OPAMP3+ADC3	OPAMP4+ADC4
STM32F302	OPAMP1+ADC1			

不能选择ADC的引脚，因为是和OPAMP共用同一个引脚





5 .MC SDK5.0 评估硬件

支持组成灵活的各类马达控制系统

灵活的各种EVB电机控制平台

EVB控制板

EVB功率板

完整的电机控制驱动板

Nucleo + X-NUCLEO板

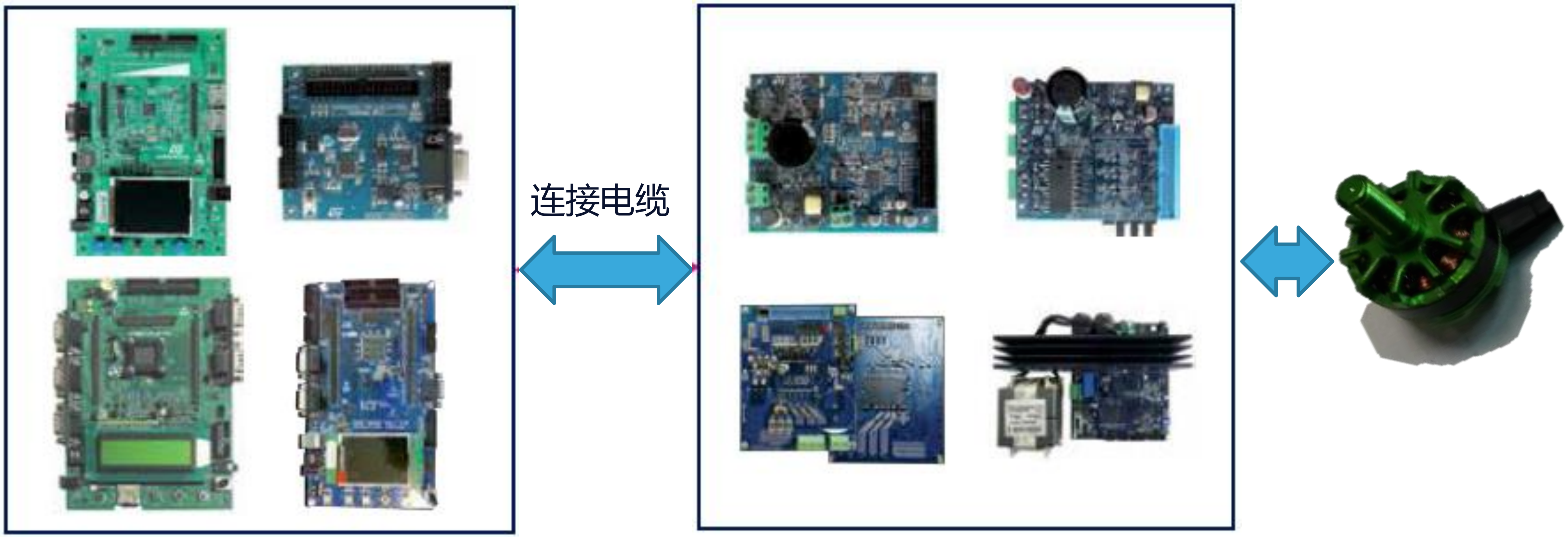
电机控制套件

包含电机

life.augmented

MCU EVB + PB EVB + Motor

- 整合的MCU EVB和功率板EVB满足客户的应用需求



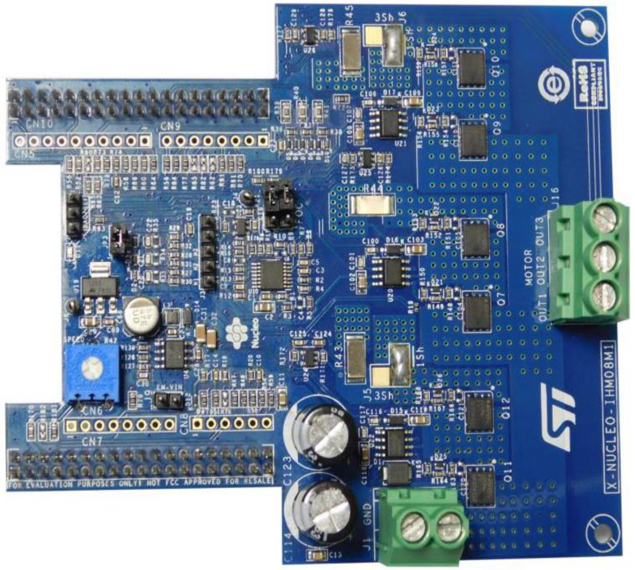
MCU EVB

功率板 EVB

电机

直流供电的NUCLEO功率板简介

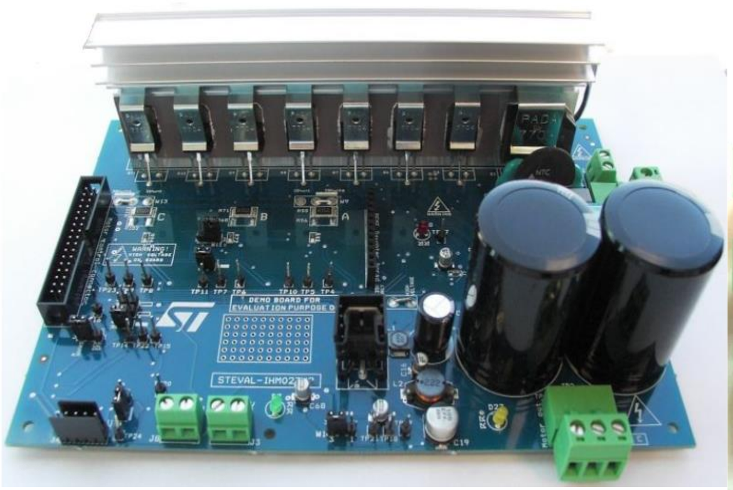
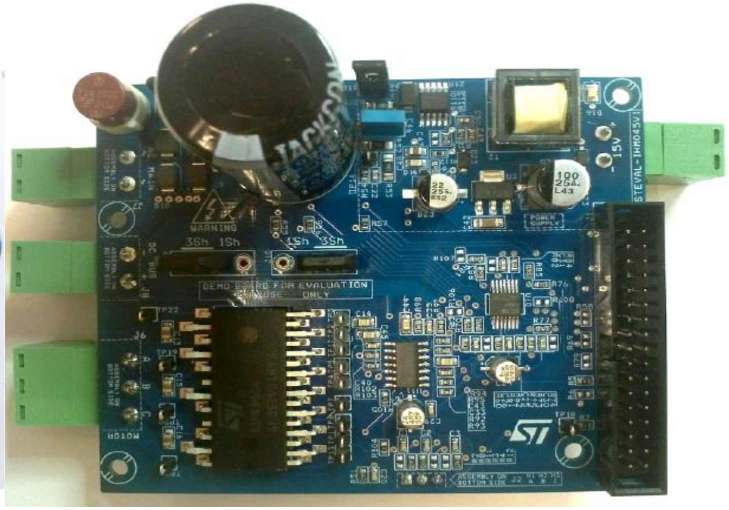
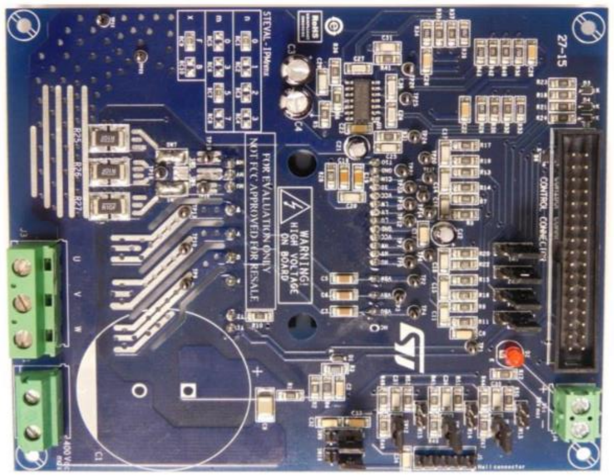
	PB Name	Power(W)/Current(A)	Voltage(V)	Motor Type/Control Type	Application
1	X-NUCLEO-IHM07M1	1.4A(2.8A)	8-48V DC	PMSM/BLDC FOC/6 Step 1/3 shunt	Drones
2	X-NUCLEO-IHM08M1	15A	10-48V DC	PMSM/BLDC FOC/6 Step 1/3 shunt	Drones,e-bikes,drills,pumps
3	X-NUCLEO-IHM11M1	1.3A	1.8-10 VDC	BLDC FOC 1 shunt	Drones



life.augmented

直流供电的EVB功率板简介

No.	PB Name	Power(W)/Current(A)	Voltage(V)	Motor Type/Control Type	Application
4	STM3210B-MCKIT	7A	42V DC	PMSM/BLDC FOC/6 Step 1/3 shunt	Drones,e-bikes,drills,pumps
5	STEVAL-IHM023V3	1KW	125-400V DC	PMSM/BLDC FOC 3 shunt	Pumps,compressors,wash machines
6	STEVAL-IHM028V2	2KW	125-400V DC	PMSM/BLDC FOC 1/3 shunt	Pumps,compressors,wash machines
7	STEVAL-IHM025V1	1KW	125-400V DC	PMSM/BLDC FOC 1/3 shunt	Pumps,compressors,wash machines
8	STEVAL-IHM045V1	100W	40-400V DC	PMSM/BLDC FOC 1/3 shunt(Dual motor)	Pumps,compressors,fans,dish washers
9	STEVAL-IPM05F	500W	125-400V DC	PMSM/BLDC FOC 1/3 shunt	Water pumps,fans,dish washers
10	STEVAL-IPM10B	1.2KW	125-400V DC	PMSM/BLDC FOC 1/3 shunt	Pumps,compressors,air conditioning
11	STEVAL-IPM15B	1.5KW	125-400V DC	PMSM/BLDC FOC 1/3 shunt	Pumps,compressors,fans,dish washers

SDK5.0 Workbench 支持的MCU列表

MCU Family	MCU Type	Target MCU	Package	Board
F3	302	STM32F302VB STM32F302VC STM32F302R8	LQFP100 LQFP100 LQFP64	- - NUCLEO-F302R8
	303	STM32F303VB STM32F303VC STM32F303ZE STM32F303VE STM32F303RE	LQFP100 LQFP100 LQFP144 LQFP100 LQFP64	- - - STM32303E-EVAL NUCLEO-F303RE
F0	030	STM32F030RC STM32F030R8	LQFP64 LQFP64	- NUCLEO-F030R8
	031	STM32F031C6	LQFP48	
	051	STM32F051R8 STM32F051C8	LQFP64 LQFP64	
	072	STM32F072VB STM32F072RB	LQFP100 LQFP64	STM32072B-EVAL NUCLEO-F072RB
F4	4xx	STM32F417IG STM32F415ZG STM32F407IG	UFBGA176 LQFP144 UFBGA176	STM3241G-EVAL STEVAL-IHM039V1 STM3240G-EVAL
	446	STM32F446ZE STM32F446RE	LQFP144 LQFP64	STM32446E-EVAL NUCLEO-F446RE

所有 SDK4.3 支持的MCU SDK5.0 最终会全部支持!

life.augmented

SDK5.0 ST 参考板(1/2)

5.0 支持的控制板

Product	MCU	Serie	Line	DIE	WB	WB Type	CubeMx board
STM32	F030R8	F0	F030	440	NUCLEO-F030R8	Control board	NUCLEO-F030R8_STM32F030R8
STM32	F072RB	F0	F072	448	NUCLEO-F072RB	Control board	NUCLEO-F072RB_STM32F072RB
STM32	F302R8	F3	F302	439	NUCLEO-F302R8	Control board	NUCLEO-F302R8_STM32F302R8
STM32	F303RE	F3	F303	446	NUCLEO-F303RE	Control board	NUCLEO-F303RE_STM32F303RE
STM32	F072VB	F0	F072	448	STM32072B-EVAL	Control board	STM32072B-EVAL_STM32F072VB
STM32	F303VE	F3	F303	446	STM32303E-EVAL	Control board	STM32303E-EVAL_STM32F303VE
STM32	F446RE	F4	F446	421	NUCLEO-F446RE	Control board	NUCLEO-F446RE_STM32F446RE
STM32	F407IG	F4	F407	413	STM3240G-EVAL	Control board	STM3240G-EVAL_STM32F407IG
STM32	F417IG	F4	F417	413	STM3241G-EVAL	Control board	STM3241G-EVAL_STM32F417IG
STM32	F446ZET	F4	F446	421	STM32446E-EVAL	Control board	STM32446E-EVAL_STM32F4446ZET
STM32	F415ZGT8	F4	F415		STEVAL-IHM039V1	Control board	

life.augmented

SDK5.0 ST 参考板(2/2)

5.0 支持的功率板

Part Number	General Description
STEVAL-IHM023V3	1 kW 3-phase motor control evaluation board featuring L6390 drivers and STGP10H60DF IGBT
STEVAL-IHM028V2	2 kW 3-phase motor control evaluation board featuring the STGIPS20C60 IGBT intelligent power module
STEVAL-IHM045V1	3-phase high voltage inverter power board for FOC based on the STGIPN3H60A (SLLIMM™-nano)
STEVAL-IPM05F	Motor control power board based on the SLLIMM™ 2nd series of IGBT IPMs
STEVAL-IPM07F	Motor control power board based on the SLLIMM™ 2nd series of IGBT IPMs
STEVAL-IPM10B	Motor control power board based on the SLLIMM™ 2nd series of IGBT IPMs
STEVAL-IPM10F	Motor control power board based on the SLLIMM™ 2nd series of IGBT IPMs
STEVAL-IPM15B	Motor control power board based on the SLLIMM™ 2nd series of IGBT IPMs
X-NUCLEO-IHM07M1	Three-phase brushless DC motor driver expansion board based on L6230 for STM32 Nucleo
X-NUCLEO-IHM08M1	Low-Voltage BLDC motor driver expansion board based on STL220N6F7 for STM32 Nucleo
X-NUCLEO-IHM11M1	Low voltage three-phase brushless DC motor driver expansion board based on STSPIN230 for STM32 Nucleo

NUCLEO和EVB的功率板及控制板组合

5.0 支持的NUCLEO功率板和控制板的组合

	NUCLEO-F302R8	NUCLEO-F303RE	NUCLEO-F072RB	NUCLEO-F446RE	NUCLEO-F030R8
X-NUCLEO-IHM07M1	√	√	√	√	√
X-NUCLEO-IHM08M1	√	√	√	√	√
X-NUCLEO-IHM11M1	√	√	√	√	√

5.0 支持的EVB功率板和控制板的组合

	STM32072B-EVAL	STM32303E-EVAL	STM3240G-EVAL	STM3241G-EVAL	STM32446E-EVAL	STEVAL-IHM039V1
STEVAL-IHM023V3	√	√	√	√	√	√
STEVAL-IHM028V2	√	√	√	√	√	√
STEVAL-IHM045V1	√	√	√	√	√	√
STEVAL-IPM05F	√	√	√	√	√	√
STEVAL-IPM07F	√	√	√	√	√	√
STEVAL-IPM10B	√	√	√	√	√	√
STEVAL-IPM10F	√	√	√	√	√	√
STEVAL-IPM15B	√	√	√	√	√	√

6 .实验2：基于MC SDK5.0 API，速度控制与电机启动停止

用户代码在main.c中

- /* USER CODE BEGIN x */

  用户代码编写区域

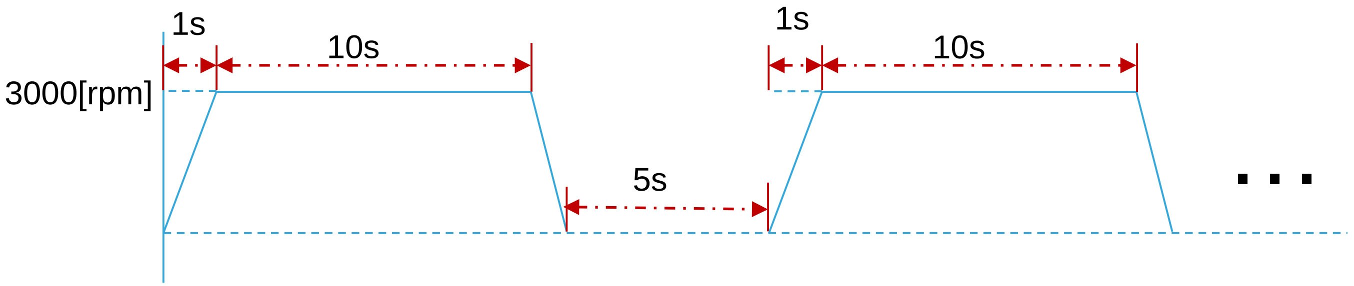
  …

- /* USER CODE END x */

(x = 0,1,2,3….)

Task1

1. 电机以3000rpm运行
2. 程序启动电机运行，运行速度为3000rpm，在10s后停止转动
3. 停止5s后电机重新运行，速度依然是3000rpm
4. 以上过程重复操作



life.augmented

Task1

1. 电机以3000rpm运行
   - MC_ProgramSpeedRampMotor1(3000/6,1000);
   - 1000ms内加速到3000RPM，3000/6：
   - 以0.1HZ作为单位的速度指令

2. 程序启动电机运行，运行速度为3000rpm，在10s后停止转动

3. 停止5s后电机重新运行，速度依然是3000rpm

4. 以上过程重复操作
   - MC_StartMotor1();-- 运行电机
   - MC_StopMotor1();--停止电机
   - 5s的操作使用定时机制产生，这里使用SysTick的500us作为延迟基础，也可以使用Timer计时，软件定时等都可以；
   - Stm32f3xx_hal.c->HAL_GetTick()

life.augmented

7. 实验3：基于MC SDK5.0 PI 组件接口函数做在线参数修改

life.augmented

Task2

1. 程序中修改速度PI参数
2. 修改为原始值的2倍
3. Workbench中观察参数修改后的速度曲线
4. 修改为原始值的0.5倍，再次观察速度曲线

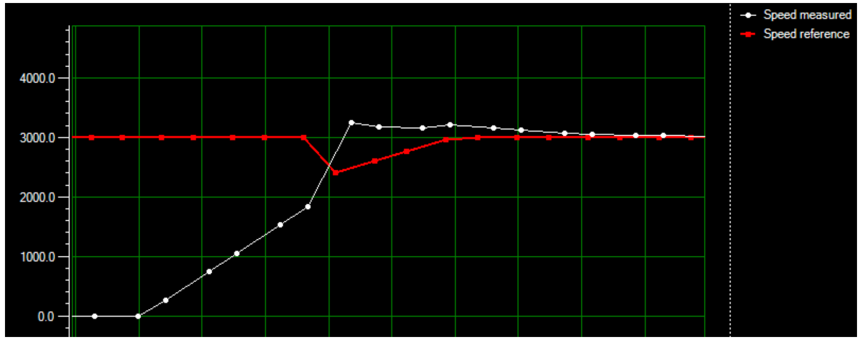
Task2

1. 程序中修改速度PI参数

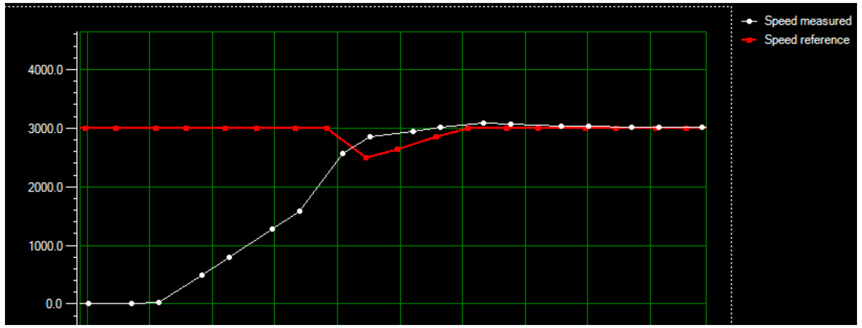
2. 修改为原始值的2倍
   - static int16_t Speed_Kp,Speed_Ki;
   - pMctHdl = GetMCT(M1);
   - Speed_Kp = PID_GetKP(pMctHdl->pPIDSpeed);
   - Speed_Ki = PID_GetKI(pMctHdl->pPIDSpeed);
   - PID_SetKP(pMctHdl->pPIDSpeed,Speed_Kp*2);
   - PID_SetKI(pMctHdl->pPIDSpeed,Speed_Ki*2);

life.augmented

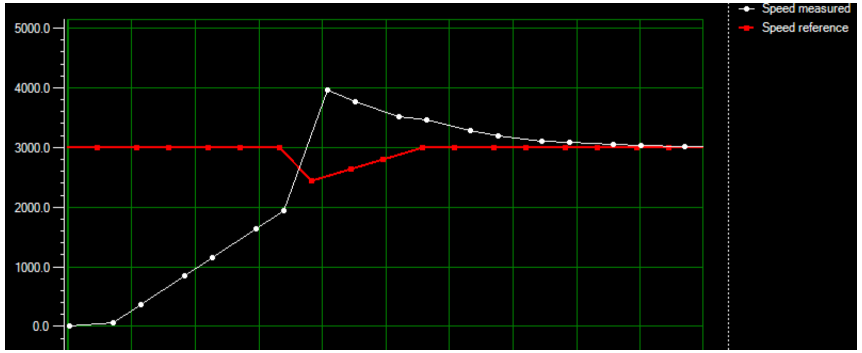
Task2



原始PID数据



2倍PID数据



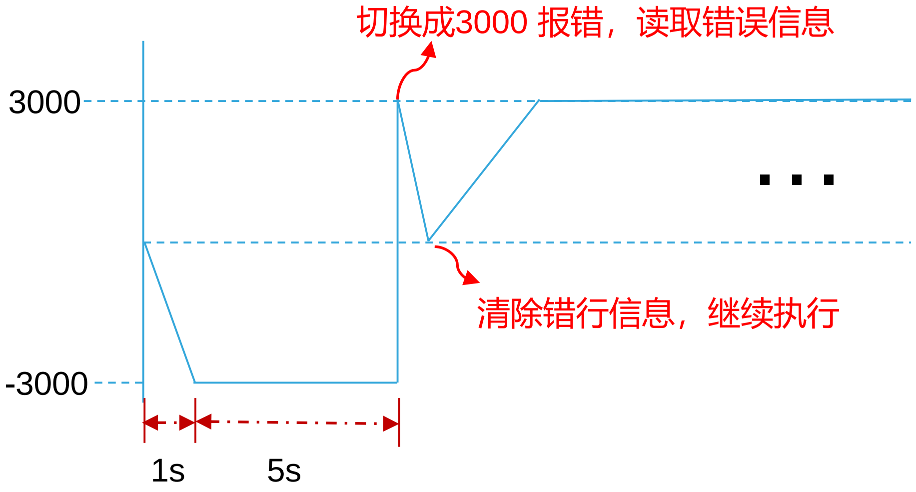
0.5倍PID数据

life.augmented

8.实验4：基于MC SDK5.0 状态的切换

Task3

1. 速度反转-3000rpm
2. 速度立刻正转3000rpm
3. 产生状态报错，需要程序返回报错信息
4. 清除报错信息，返回到IDLE状态
5. 然后继续执行正转3000rpm速度指令



life.augmented

Task3

1. 速度正转3000rpm
    - MC_ProgramSpeedRampMotor1(3000/6,1000);--正转3000RPM

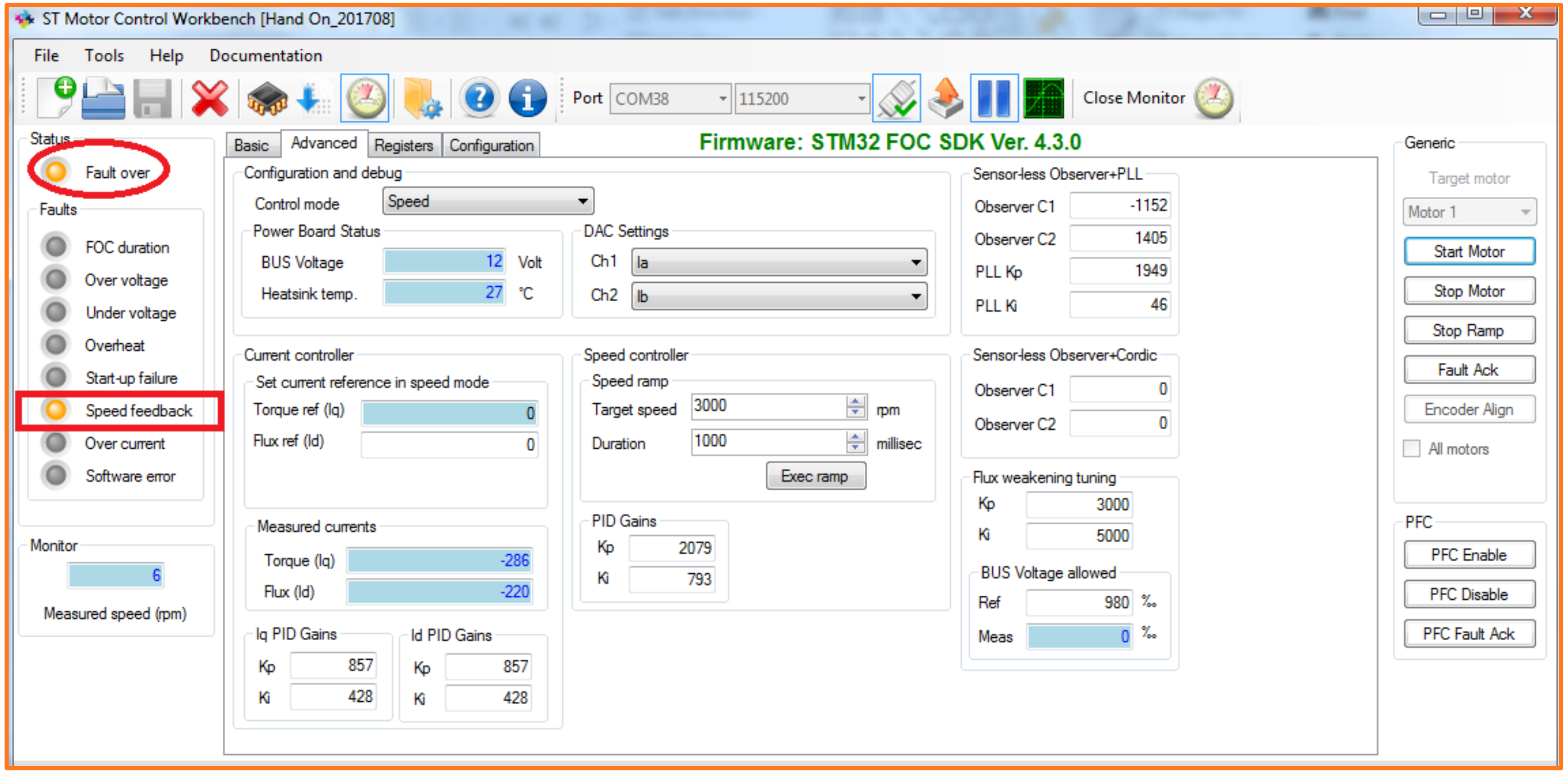
2. 速度立刻反转-3000rpm
    - MC_ProgramSpeedRampMotor1(-3000/6,1000);--反转3000RPM

life.augmented

Task3

3. 产生状态报错，需要程序返回报错信息

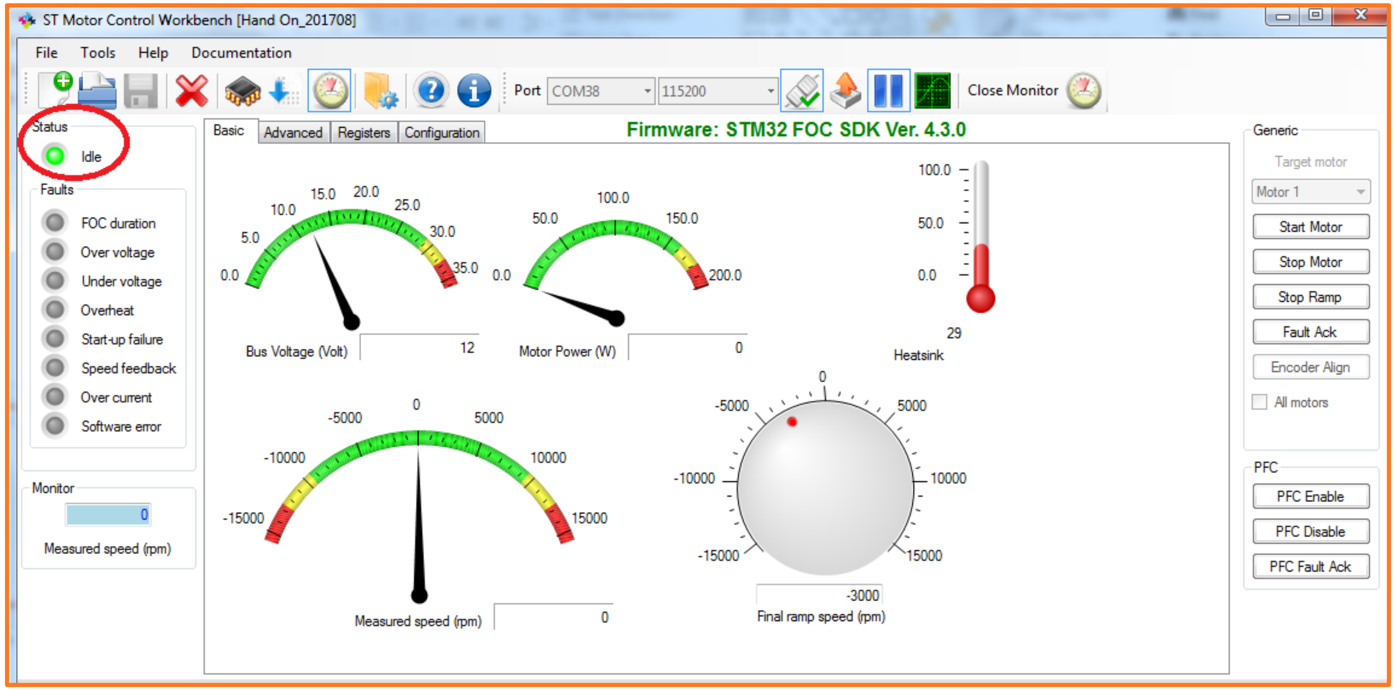
- State t sts_motor1 = MCI_GetSTMStateMotor1();
- STM_GetFaultState(&STM[M1]);



life.augmented

Task3

- 4. 清除报错信息，返回到IDLE状态
- 5. 然后继续执行反转-3000rpm速度指令
  - MC_AcknowledgeFaultMotor1();
  - MC_ProgramSpeedRampMotor1(MC_GetLastRampFinalSpeedMotor1(), 1000);



9.实验5：开放性试验

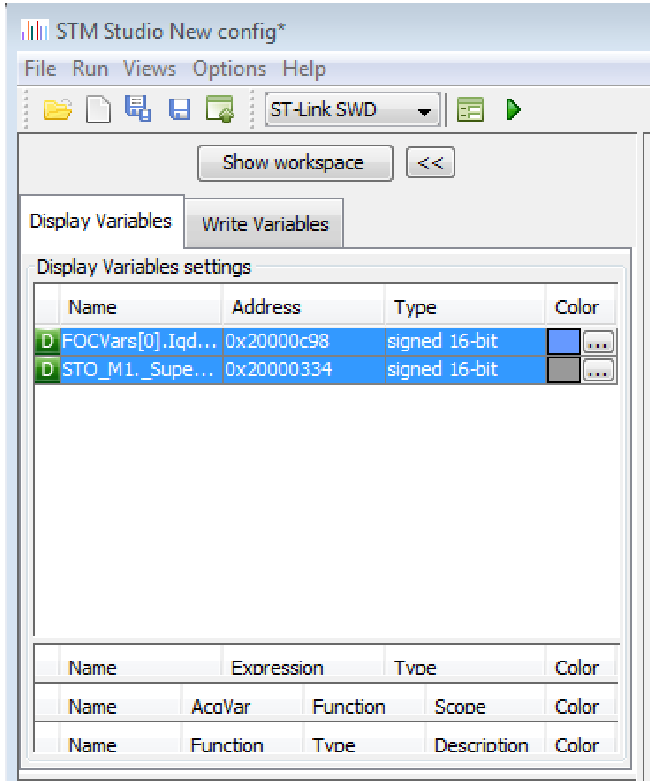
开放性试验

1. 程序控制Idref，Iqref
2. 使用STMStudio对变量改变进行观测
3. 旋钮ADC采样（PB1）对应到Iqref的变化上(Torque Mode)
4. 观察速度以及Studio上的变量变化
5. 可以加入自己想要得到的信号变量

开放性试验

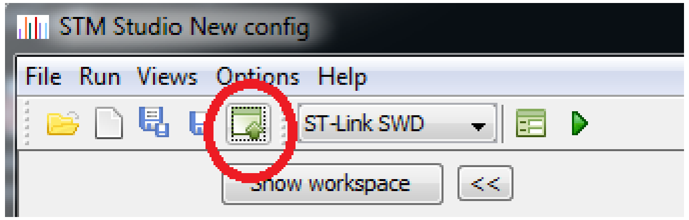
1. 程序控制Idref，Iqref
    - MC_ProgramTorqueRampMotor1(Tuning_Iqref,1000);

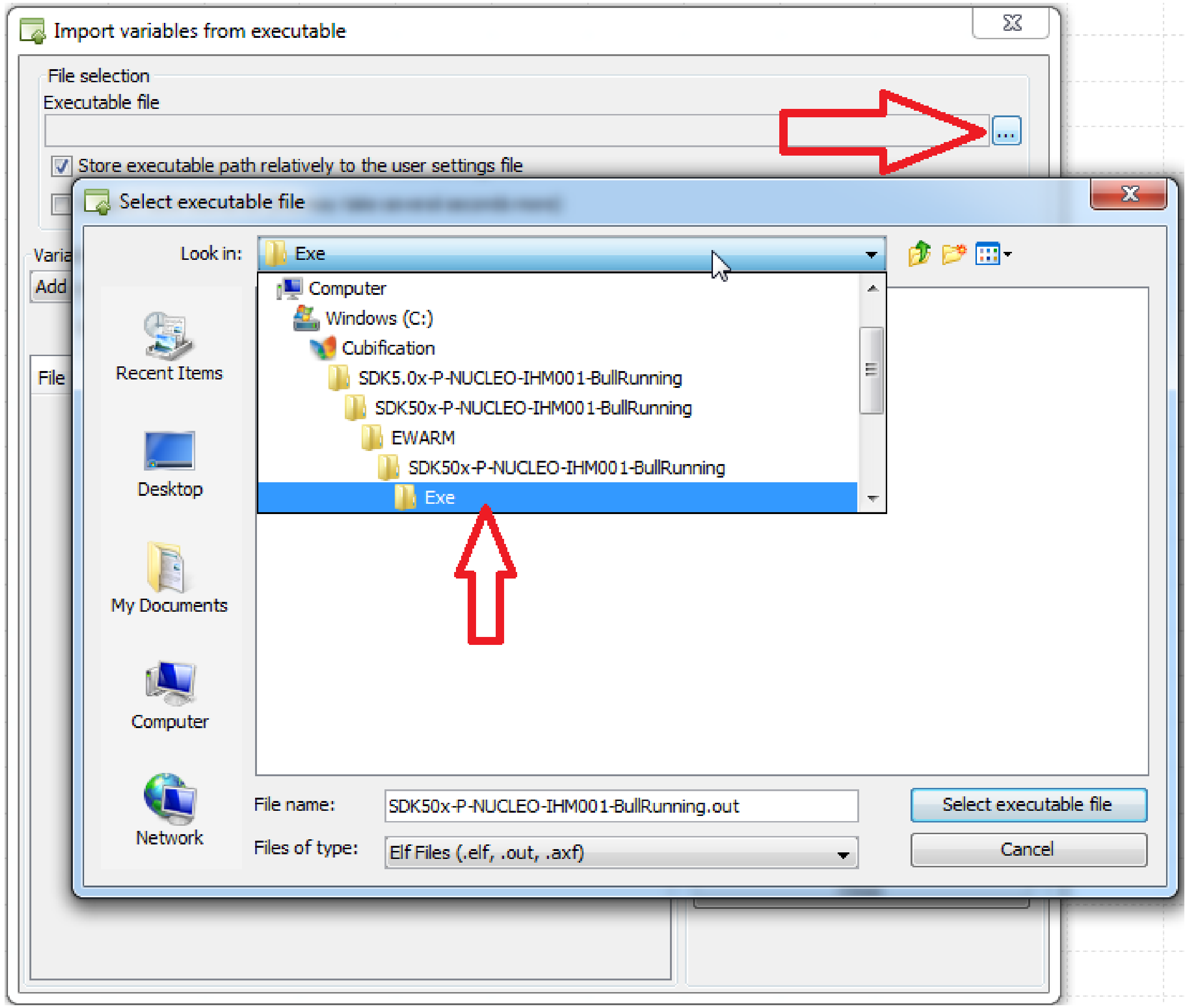
- 2. 使用STMStudio对变量改变进行观测



life.augmented

- STMStudio添加.out文件装载
  - SDK50x-P-NUCLEO-IHM001-BullRunning.out





life.augmented

开放性试验

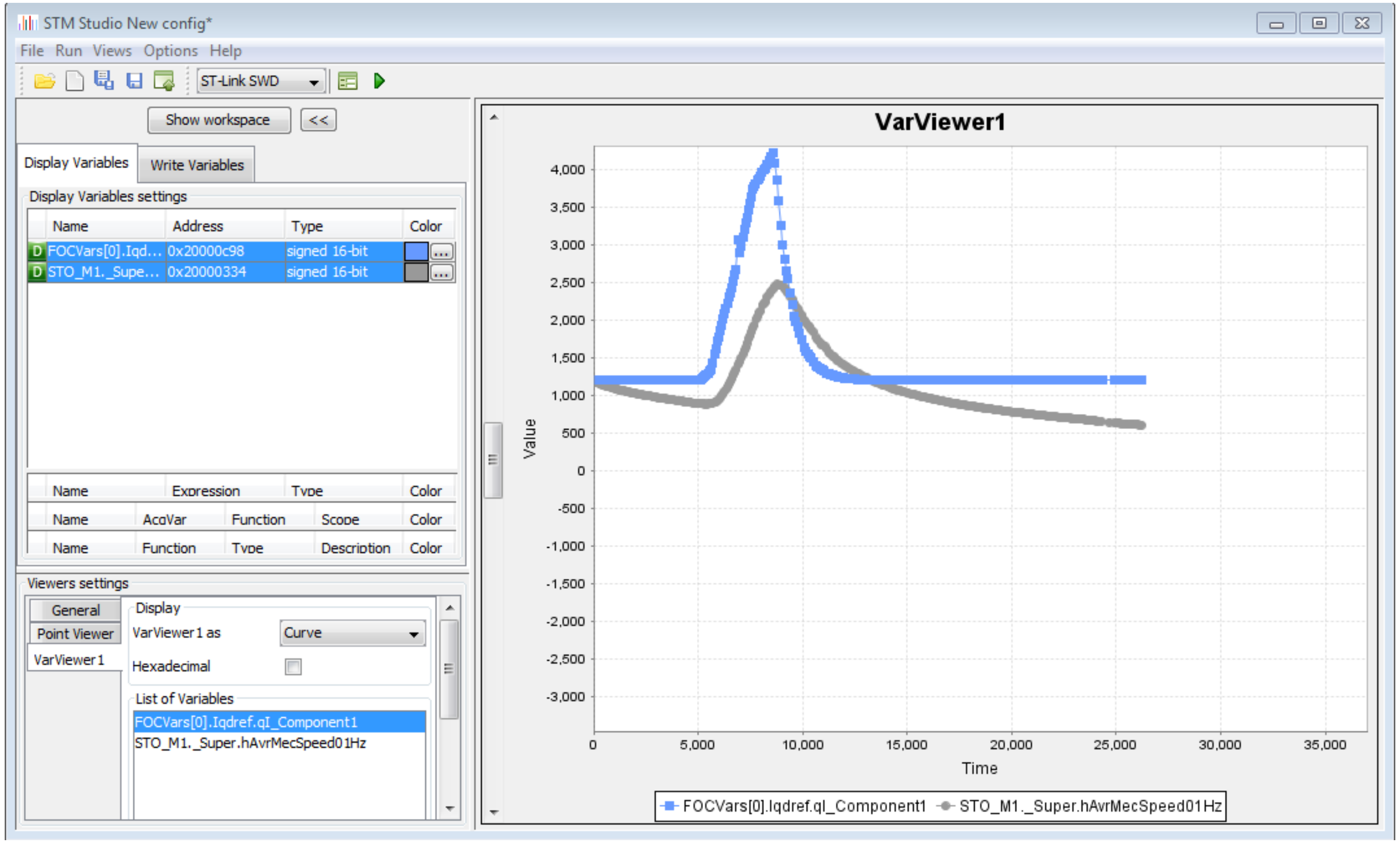
- 3. 旋钮ADC采样（PB1）对应到Iqref的变化上
  - MC_ProgramRegularConversion(ADC_Channel_12, ADC_SampleTime_601Cycles5);
  - MC_GetRegularConversionValue();

```
void Open_Task( void )
{
  pMciHdl = GetMCI( M1 );

  /* Do regular adc convert*/
  if( MC_GetRegularConversionState() == UDRC_STATE_IDLE )
  {
    MC_ProgramRegularConversion( ADC_CHANNEL_12, ADC_SAMPLETIME_601CYCLES_5 );
  }
  else if( MC_GetRegularConversionState() == UDRC_STATE_EOC )
  {
    /* Get ADC value*/
    Tuning_ADC = MC_GetRegularConversionValue();
  }

  if(Delay_Count == 0)
  {
    Delay_Count = HAL_GetTick();
  }
  else if(HAL_GetTick() > (Delay_Count + 1))
  {
    Delay_Count = 0;

    /* Get new Iqref*/
    Tuning_Iqref = ( Tuning_ADC + 1 ) * MAX_TUNING_IQ / 65536;

    if( Tuning_Iqref < MIN_TUNING_IQREF )
    {
      Tuning_Iqref = MIN_TUNING_IQREF;
    }
    /* Set new Iqref ramp*/
    MC_ProgramTorqueRampMotor1( Tuning_Iqref, 1000 );
    MC_StartMotor1();
  }
}
```

life.augmented

开放性试验

- 旋转Demo板上旋钮改变Iqref，察看速度和Iqref数据



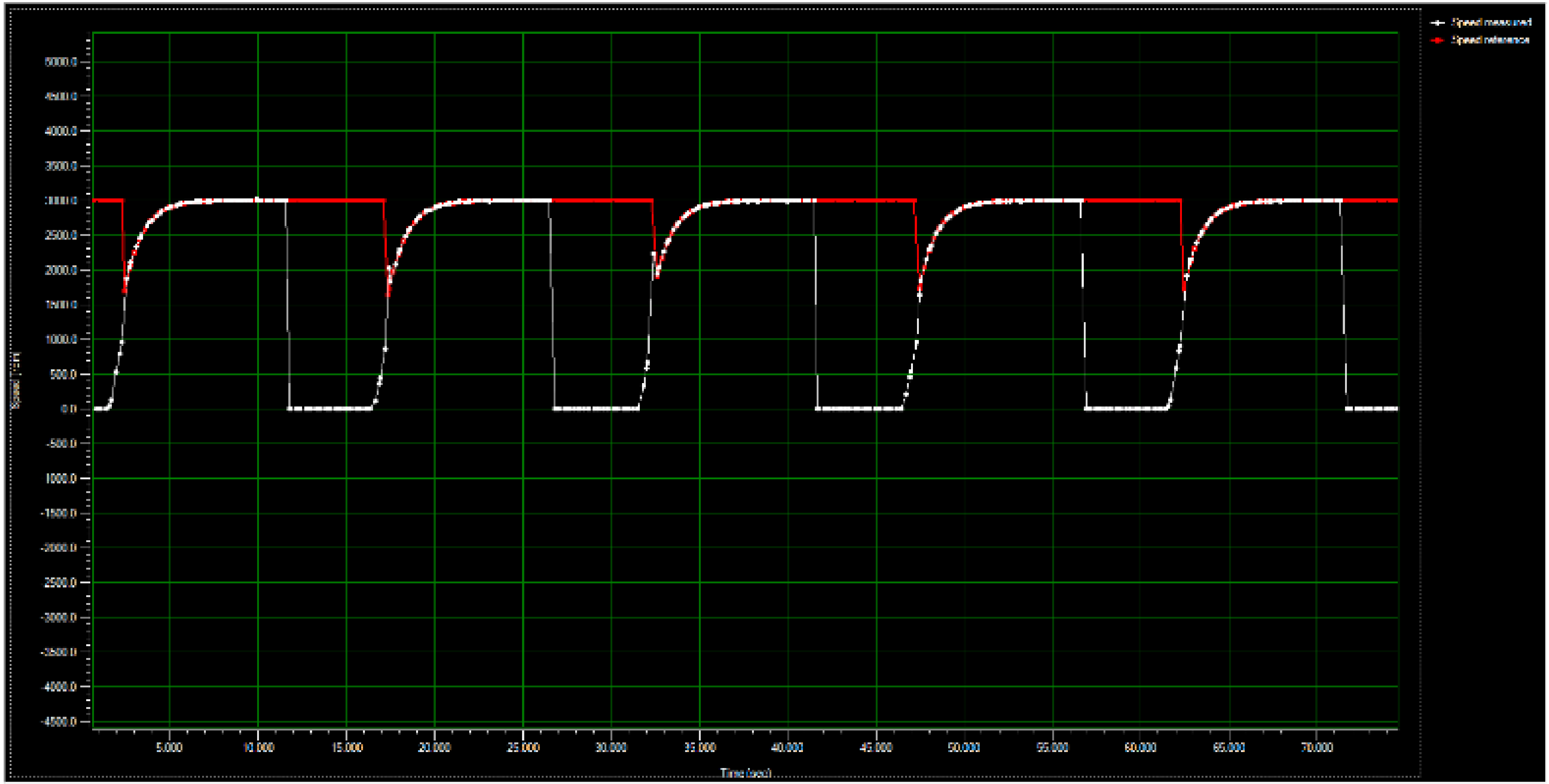
life.augmented

10.实验总结及问答

实验总结

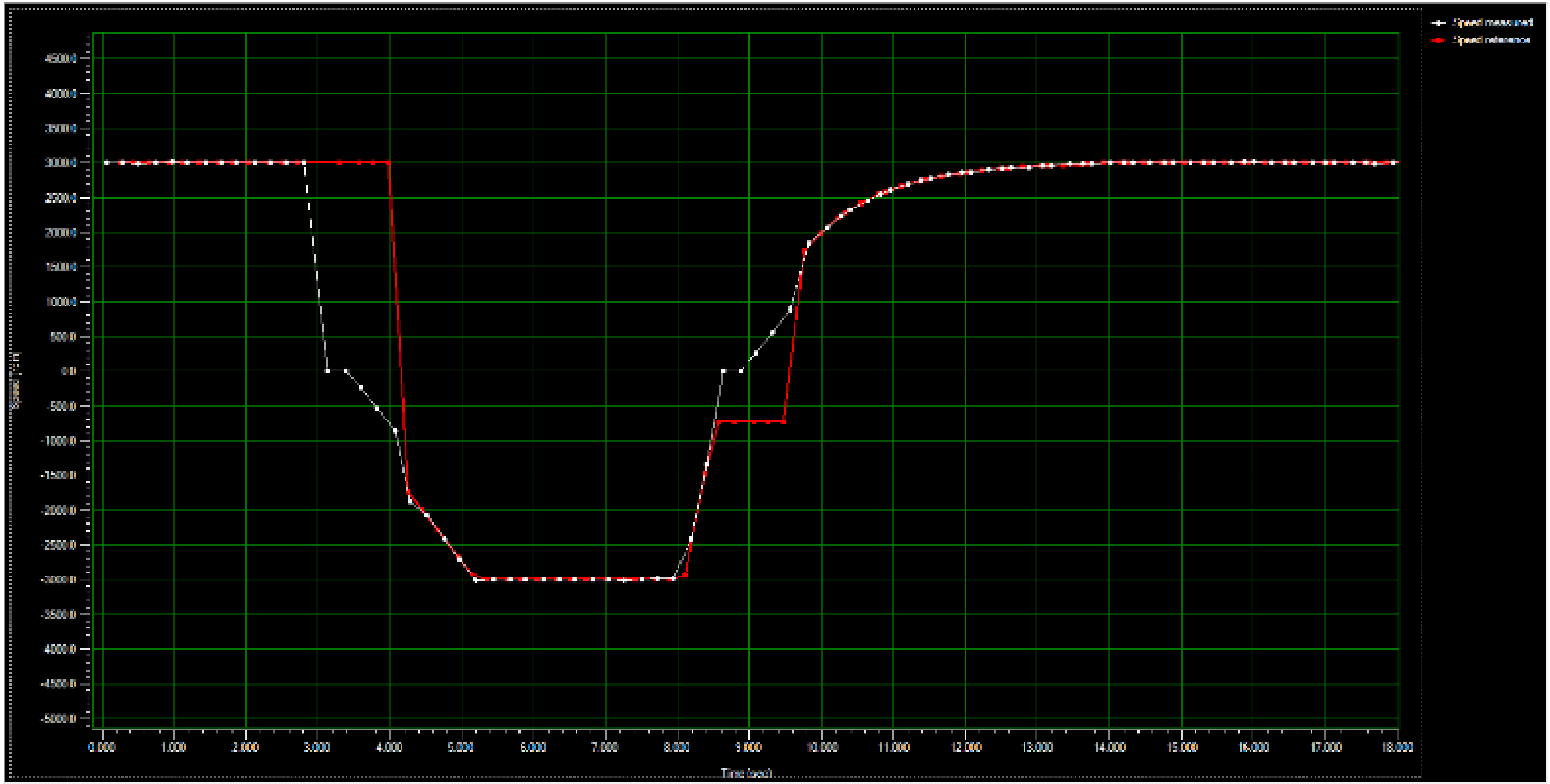
项目	目的	说明
Task1	熟悉调用MCI实现电机基础操作	启动电机 -- MC_StartMotor1()
		停止电机 -- MC_StopMotor1()
		速度指令 -- MC_ProgramSpeedRampMotor1(3000 / 6, 1000)
	了解速度参数设定	参考速度指令是以0.1HZ作为单位
Task2	取得MCT句柄	pMctHdl = GetMCT(M1)
	知道如何找到相关操作函数	比如PID设定在pid_regulator.c中
	调用控制函数以及参数设定	取得当前数据 -- PID_GetKP(pMctHdl->pPIDSpeed)
		修改数据 -- PID_SetKP(pMctHdl->pPIDSpeed,Speed_Kp*2)
	Workbench观察速度曲线	操作在Workbench中
Task3	电机反转指令	MC_ProgramSpeedRampMotor1(-3000 / 6, 1000)
	调用函数知道当前电机运行状态	State_t sts_motor1 = MCI_GetSTMStateMotor1();
	得到报错信息	STM_GetFaultState(&STM[M1])
	清除报错，电机回到IDLE状态	MC_AcknowledgeFaultMotor1()
	Workbench做状态监控	注意Workbench状态变化
Open	使用力矩模式控制电机	MC_ProgramTorqueRampMotor1(Tuning_Iqref, 1000)
	旋钮ADC通道采样	MC_ProgramRegularConversion(ADC_CHANNEL_12, ADC_SAMPLETIME_601CYCLES_5)
	熟悉ST Studio使用	软件操作

Task1



life.augmented

Task3


Speed measured
Speed reference
4500.0
4000.0
3500.0
3000.0
2500.0
2000.0
1500.0
1000.0
500.0
0.0
-500.0
-1000.0
-1500.0
-2000.0
-2500.0
-3000.0
-3500.0
-4000.0
-4500.0
-5000.0
0.000
1.000
2.000
3.000
4.000
5.000
6.000
7.000
8.000
9.000
10.000
11.000
12.000
13.000
14.000
15.000
16.000
17.000
18.000

重要通知 – 请仔细阅读

意法半导体公司及其子公司（“ST”）保留随时对ST 产品和/ 或本文档进行变更、更正、增强、修改和改进的权利，恕不另行通知。买方在
订货之前应获取关于ST 产品的最新信息。ST 产品的销售依照订单确认时的相关ST 销售条款。

买方自行负责对ST 产品的选择和使用， ST 概不承担与应用协助或买方产品设计相关的任何责任。

ST 不对任何知识产权进行任何明示或默示的授权或许可。

转售的ST 产品如有不同于此处提供的信息的规定，将导致ST 针对该产品授予的任何保证失效。

ST 和ST 徽标是ST 的商标。所有其他产品或服务名称均为其各自所有者的财产。

本文档中的信息取代本文档所有早期版本中提供的信息。

life.augmented

谢谢大家!