Title	Sensorless Velocity Control for PMSM		
Number		**Device**	S300/S700
Author	Juan C. Ramirez Martinez	**Module**	
Date		**Firmware**	5.55
Page	14	**Function**	Sensorless

0.1 Application Note - Sensorless

This application note describes the feature Sensorless for PMSM in a Servostar S300/S700.

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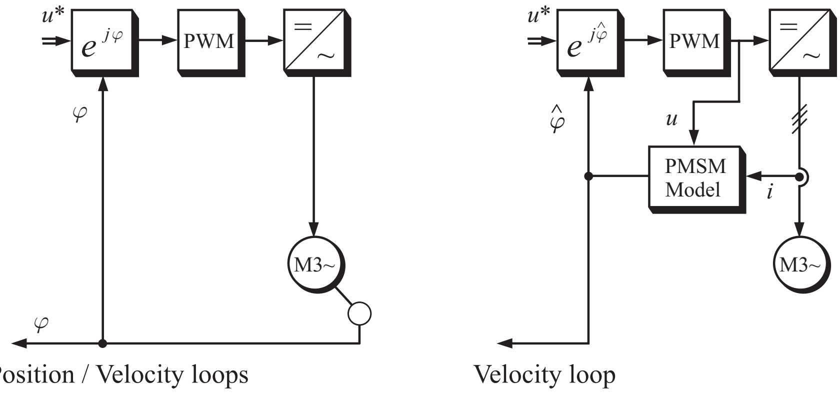
- Introduction
- Tuning stepper and sensorless feature
- Summary of parameters
- Results when sensorless is working
- Help when sensorless is not working

0.1.1 Introduction

Sensorless is a method that allows the operation of electrical machines without needing a feedback sensor (See Fig. 0.1). To close the loop, the feedback signal is estimated. Such estimation depends of which kind of sensorless is being applied. In our case, sensorless is based on a reduced machine model. In a few words, when the orientation is not correct (false angle) a Back-EMF (Electromagnetic force) is present at d-axis. Based on that principle, position will be estimated and used as control variable. As soon as sensorless detects that BEMF in D is close to zero, then the position will be considered as correct. When a disturbance appears, a BEMF will appear again in d-axis and sensorless will try to reduce this BEMF controlling the position as mentioned.



(a) Typical feedback solution with sensor

(b) Sensorless

Figure 0.1: Sensor and sensorless modes

Most of the S700 Servo-drive applications are considered to be of high-performance and such high-dynamic can be just reached using a sensor. On the other side, sensorless-dynamic is considerably slower than sensor-dynamic. Therefore:

- Sensorless-mode is not a substitute or replacement for sensor-mode and actually it should only be considered as an option
- Eliminating a sensor and using sensorless is not a way to reduce costs
- Sensorless should be used in applications of limited dynamic and when the use of sensor is complicated
- A sensorless axis performs best if it runs close to nominal speed. The machine in sensorless mode should be chosen that the velocity range of the application is higher than 50% of the nominal speed of the machine
- Sensorless should not be applied for positioning applications

0.1.2 Tuning stepper and sensorless feature

In the following steps, a general protocol to tune sensorless is described.

1. In DriveGUI-Feedback window select Feedback Type = 10 Sensorless and ensure that SLMODE is set to 1. If not, do it manually, typing SLMODE = 1 in terminal page

2. Because sensorless-mode is not as dynamic as sensor-mode, the slopes for SLACCMAX, ACC and DEC should be slow. At the beginning, try at most SLACCMAX = ACC = DEC = 600rad/s^2. If this value shows troubles at transition point, make the slopes slower, specially the value for SLACCMAX

3. At this point, parameters for current controller (MLGQ & KTN) and for velocity controller (GV & GVTN) are already set, maybe according to the Motor-Name or set by the user. Most of the parameters have not big influence in sensorless performance, but GV and specially GVTN. As mentioned, sensorless-mode is not as dynamic as sensor-mode. For that reason, the proportional part of the velocity controller (GV) should be small and integral part (GVTN) should be slow. For GVTN, values under 30ms will crash the sensorless completely. A value around 100ms is expected to show good performance

4. As a matter of principle back-EMF, sensorless mode cannot work at zero or very low speeds. Therefore at zero and low speeds, a feed-forward stepper-mode is used. The user should set two parameters to decide a threshold velocity (SLJSWITCH) and a transition time (SLTSWITCH) between stepper and sensorless modes. For SLJSWITCH a value of 10% nominal speed or higher is mandatory. SLTSWITCH defines a time in which the motor remains at speed SLJSWITCH to let the observer integrators settle (grey line in Fig. 0.2). SLTSWITCH can often be set to zero so that the transition will be done instantaneously (black line in Fig. 0.2). SLTSWITCH can be used only in the acceleration slope, while SLJSWITCH is present in acceleration and deceleration slope as well

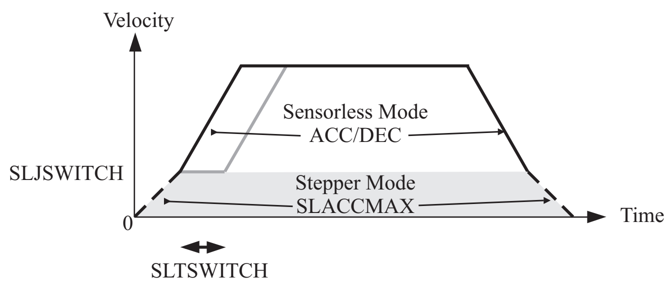


Figure 0.2: Transition between stepper and sensorless mode

5. In stepper-mode a current defined by $id^* =$ MIMR is injected in the machine windings. Being MIMR the unique manipulated variable here, a value for MIMR = 30% MICONT is advisable. However, if this current is not high enough to generate the required torque and make the motor rotate in stepper-mode, then this value should be increased.

6. Mostly, sensorless-mode depends of three parameters: SLIDK01, SLIQK & SLIQK1. The range of values SLIDK01 goes from 0 up to 1. Be aware that values close to 1 would generate faults (over speed, commutation error, etc.). While SLIDK01 = 0 does the motor just working on stepper mode until velocity limit SLJSWITCH (See Fig. 0.3). For some applications, it is sufficient to run the drive only in stepper mode. This is one possibility, just set SLJSWITCH=VLIM. But be aware, stepper mode is not a close-loop control. For the beginning set SLIQK & SLIQK1 to zero and start tuning SLIDK01. Set a value of SLIDK01 = 0.1 and if the motor does not move or stop after some seconds (similar to Fig. 0.17) then increase SLIDK01. For SLIDK01 a value between 0.1 and 0.3 is expected to develop a good performance

7. After SLIDK01 is already done, SLIQK and SLIQK1 should be set according to the following values that were obtained from experimental results. SLIQK1 = 1 and SLIQK should be select according to the model of S700 and Table 0.1

8. Other parameter that should be also fixed for sensorless is the band-width for the observer (MRESBW). A value of 50Hz or lesser (at least 30Hz) is recommended

S300 /S700 Model	SLIQK factor
701	1
706	4
712	8
724	10
748	20
772	30

Table 0.1: Values for SLIQK

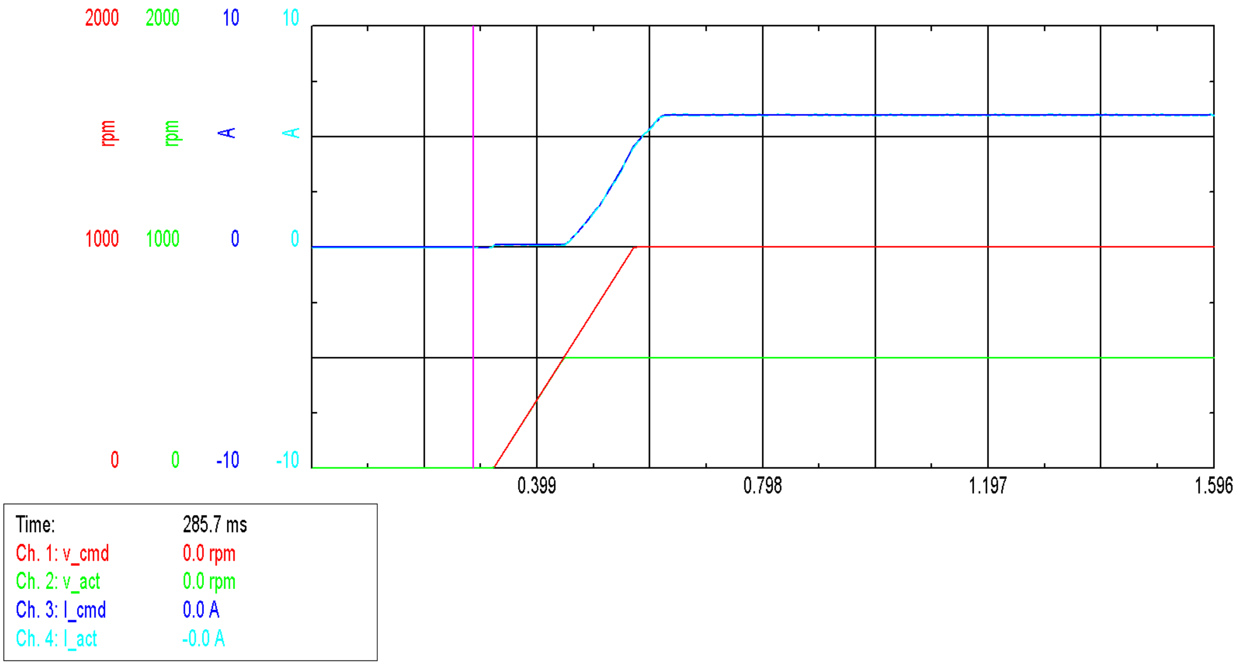


Figure 0.3: Velocity response when SLJSWITCH = 500rpm, SLIDK01 = 0 and J = 1000rpm

0.1.3 Summary of parameters

A summary of all parameters that should be taken in account for sensorless is shown in Table 0.2. Here an example set for a S712 and a motor 6SM37L4000. The recommended values are also shown.

Parameter	Set value	Units	Recommended value
SLMODE	1	–	1
SLIDK01	0.23	–	0.1<SLIDK01<0.3
SLIQK	8	–	See Table 0.1
SLIQK1	1	–	1
SLTSWITCH	0	ms	–
SLJSWITCH	200	rpm	10 % of MSPEED
SLTEMPM	0	–	0
SLACCMAX	418	rad/s^2	at most 600
ACC	418	rad/s^2	at most 600
DEC	418	rad/s^2	at most 600
MRESBW	50	Hz	at most 50
MIMR	0.9	A	30 % of MICONT
MVR	0	rpm	0
VLIM	4000	rpm	–
GV	0.053	A s/rad	–
GVTN	100	ms	100
MLGQ	90	V/A	–
KTN	0.725	ms	–

Table 0.2: Main parameters that affect sensorless performance

0.1.4 Results when sensorless is working

The following results are the conclusion of several tests. A summary of the results with a S712 using a 6SM37L4000 as motor and a 6SM37S6000 (KT = 0.5Nm/A) as load machine will be presented here:

No load and a velocity reference of 3000rpm

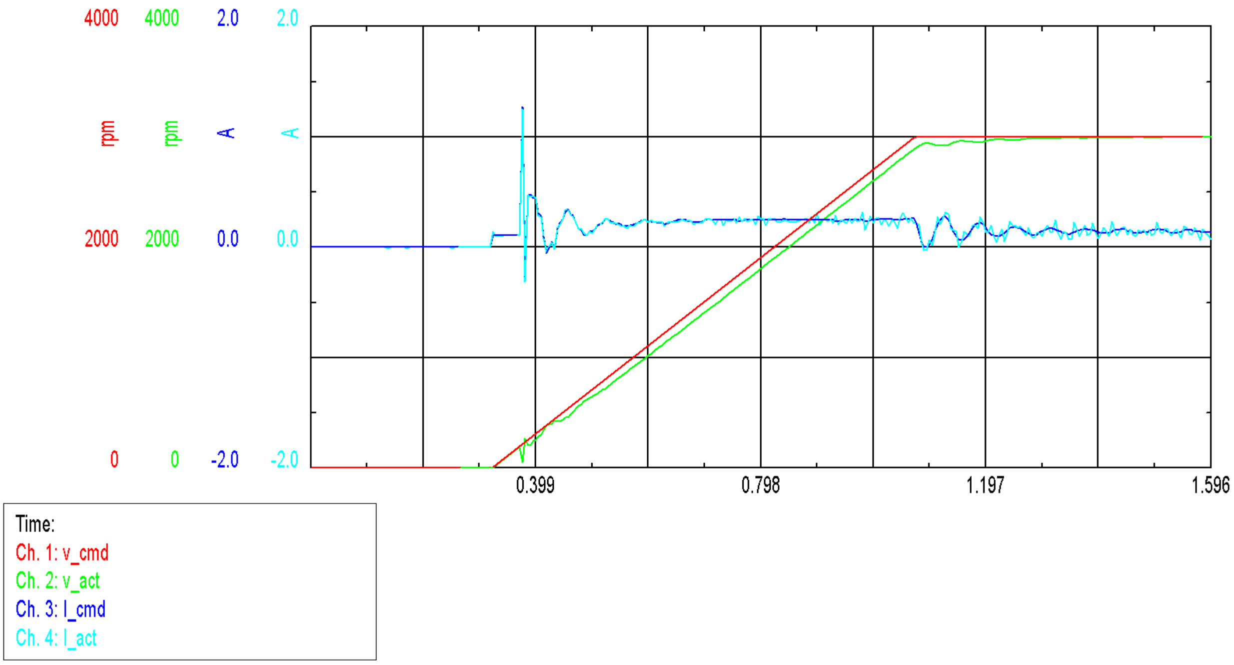


Figure 0.4: Velocity response

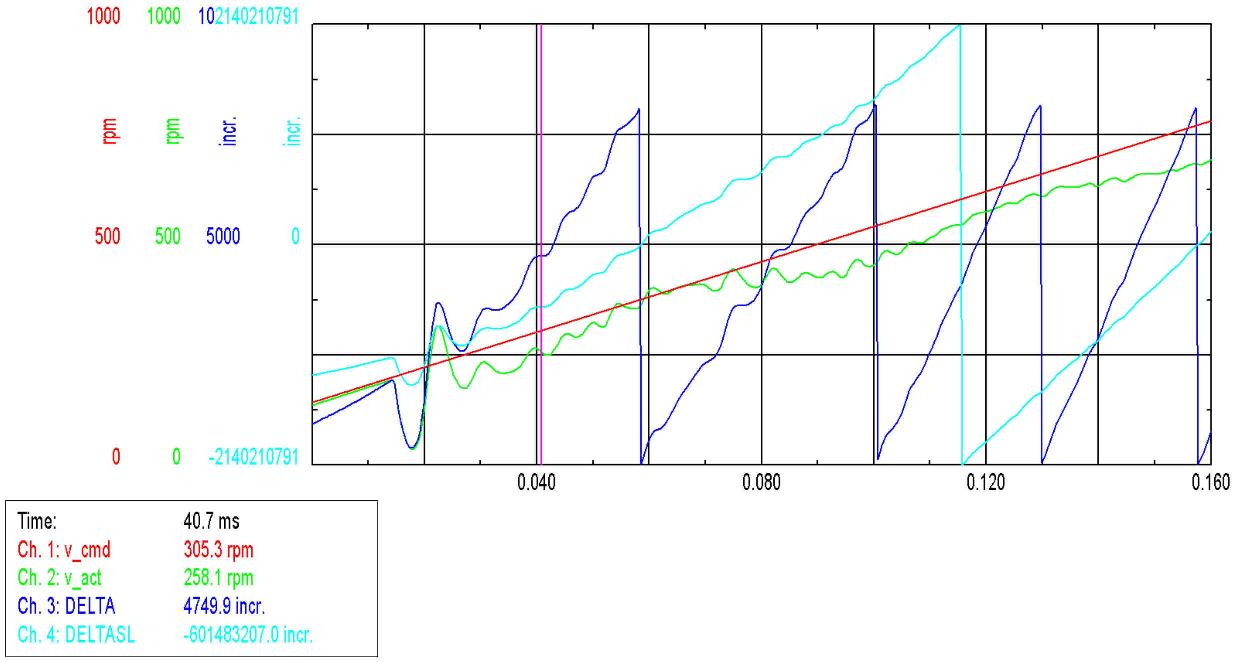


Figure 0.5: Estimated position DELTASL

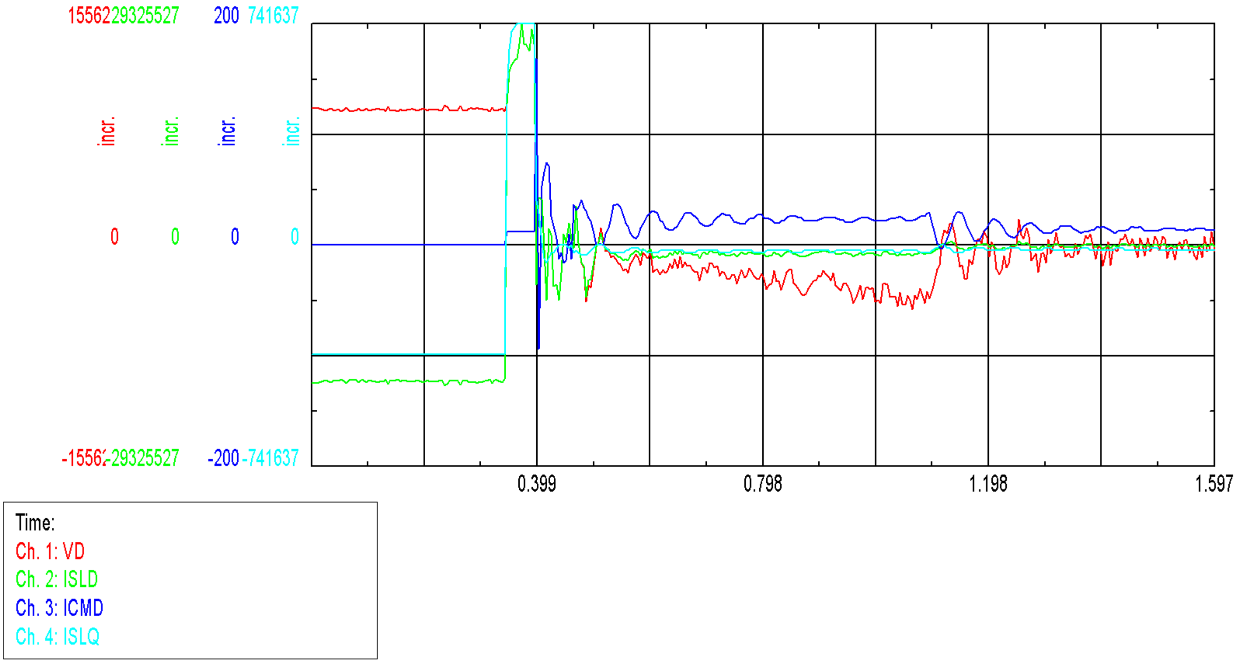


Figure 0.6: Transition point at approximately 0.4s (J = 3000rpm)

Most of the sensorless difficulties are present at transition point. Taking a look carefully at Figs. **??** and 0.6 can help you to identify where difficulties come from.

No load and change in velocity reference from 3000rpm to 3600rpm

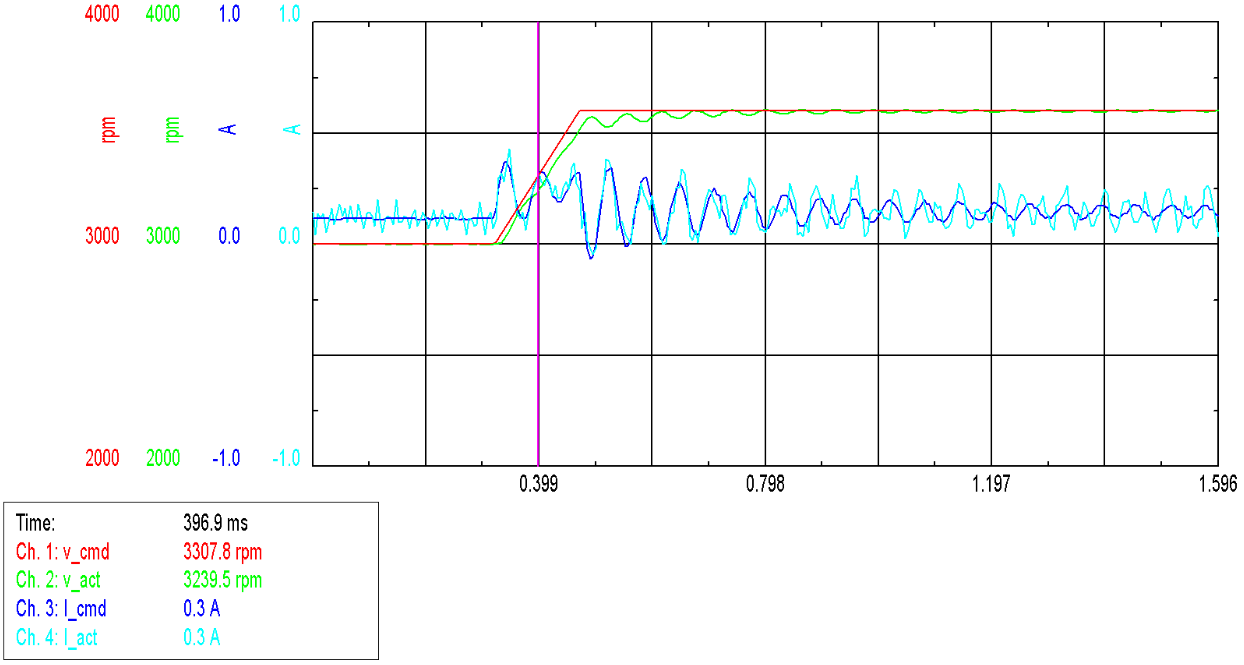


Figure 0.7: Velocity response

With load. The "load" machine is set to OPMODE = 2 and a load torque of T = 0.1Nm is applied at the beginning

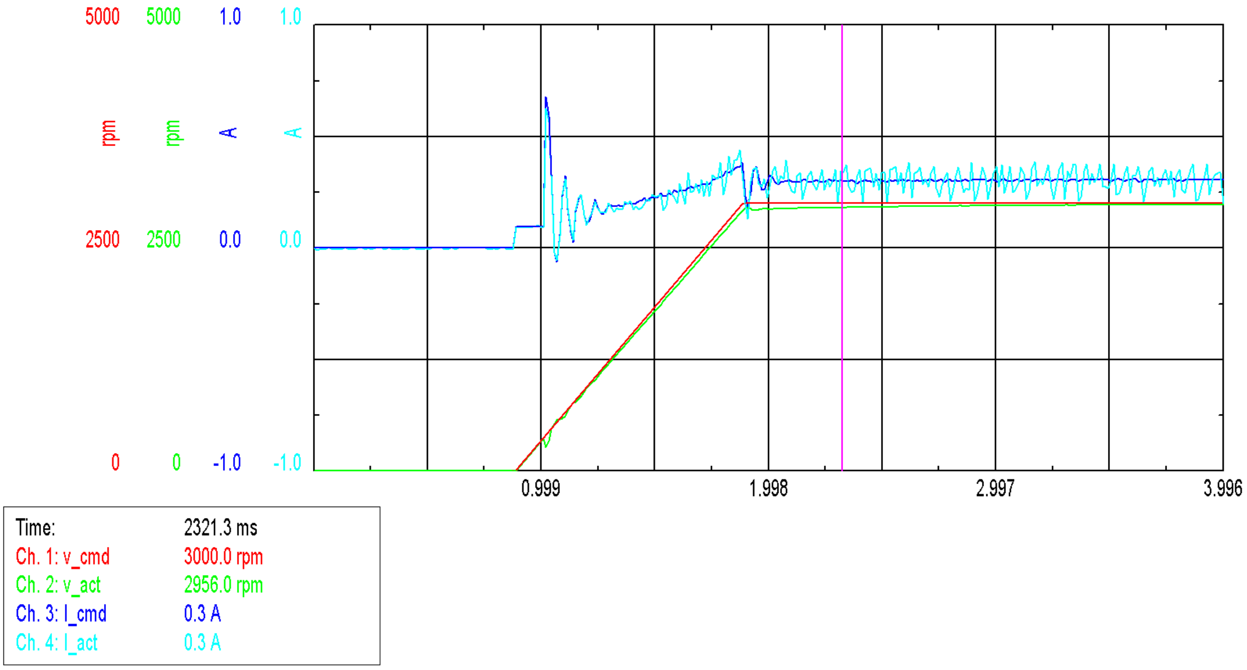


Figure 0.8: Velocity response

With load T = 0.1Nm applied when the motor is already rotating

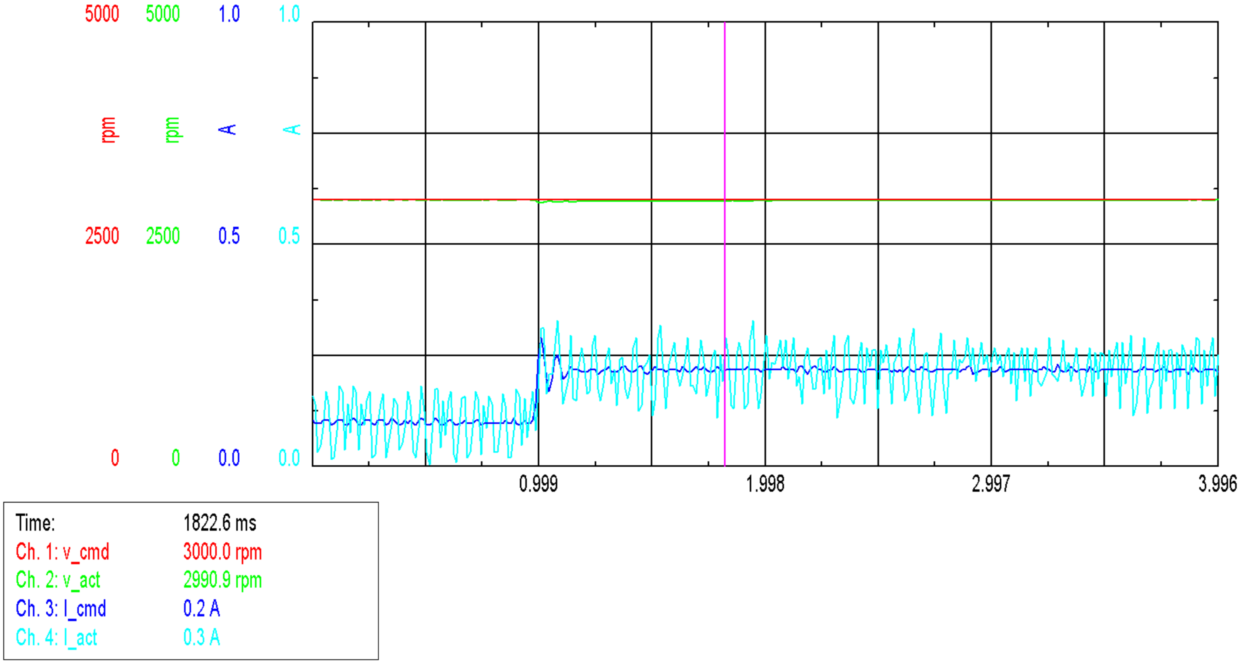


Figure 0.9: Velocity response

With a "load torque profile" of T = 0.1 Nm and t = 1500s, applied at the beginning

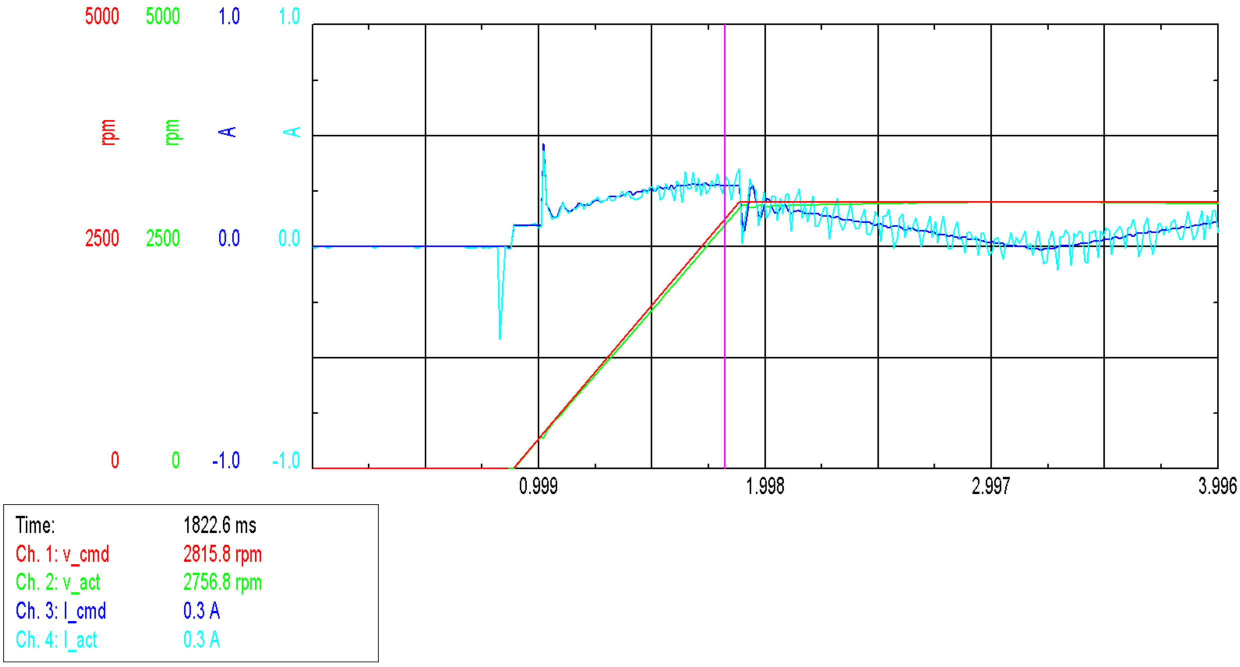


Figure 0.10: Velocity response

Here with the most complex cases, which means:

- Slow velocity. 12.5% of the nominal speed = 500rpm
- Maximal load torque from the machine T = 0.5Nm (see Fig. 0.11)
- And fast transition of the load, in this case 750ms (see Fig. 0.12)

Warning: A velocity command of 12.5% of the nominal speed is really too slow for reliable continuous sensorless operation. It is used here **only** for demonstration at the lowest limit.

Naturally the response from Fig. 0.11 is not as good as the response using sensor. Here some conclusions:

- Sensorless is able to keep operating the machine, even when the velocity reference is only 12.5% of the nominal speed. But this is only an example of the lowest limit and should not be used as reference for real operation
- Besides, the velocity in Fig. 0.11 cannot be considered as controlled
- The load is changing quickly, but it is not reason to lose the position for the field oriented control

Also, as mentioned before, this is an example and should not be considered for real operation.

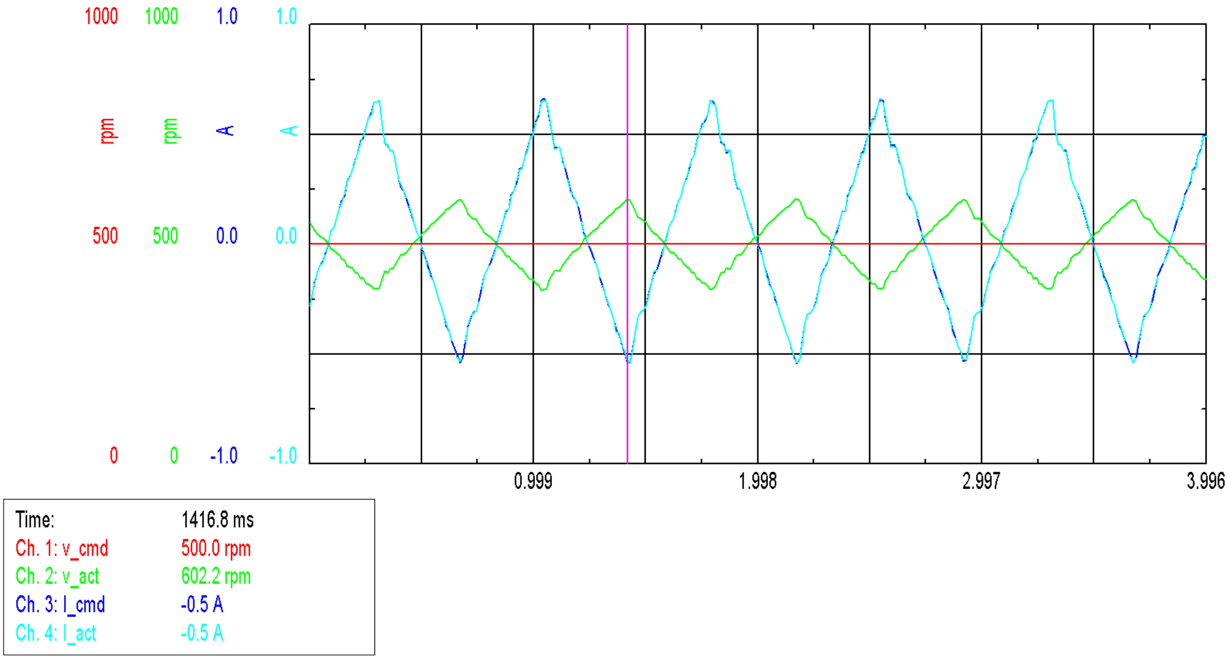


Figure 0.11: Sensorless response with a profile load torque and 12.5% nominal speed

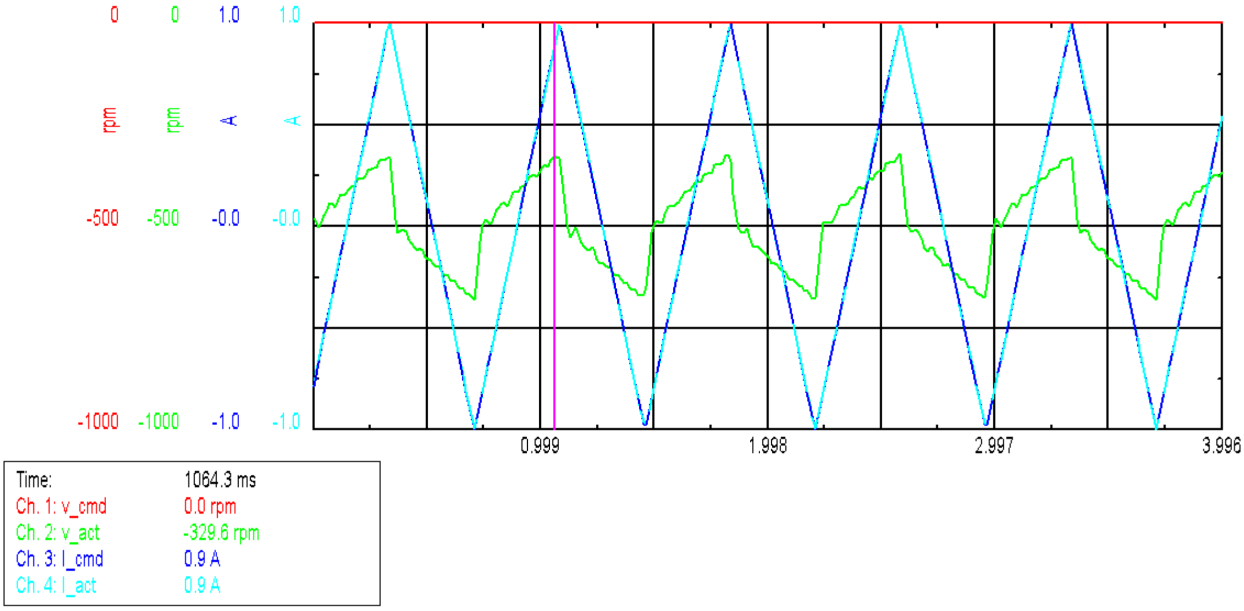


Figure 0.12: Profile of load torque

0.1.5 Help when sensorless is not working

In the following section, several problematic cases will be shown and possible solutions as well.

GVTN is too small

Using the parameters of Table 0.2, but GVTN = 6ms. Setting a velocity reference of 3000 rpm.

Fig. 0.13 shows a plot of velocity response. SLJSWITCH = 200 is the transition point, where the position is lost. Here a lot of possible combinations for SLIDK01 & SLIQK and different values for SLJSWITCH were tested without positive results. The unique solution is a bigger value of GVTN.

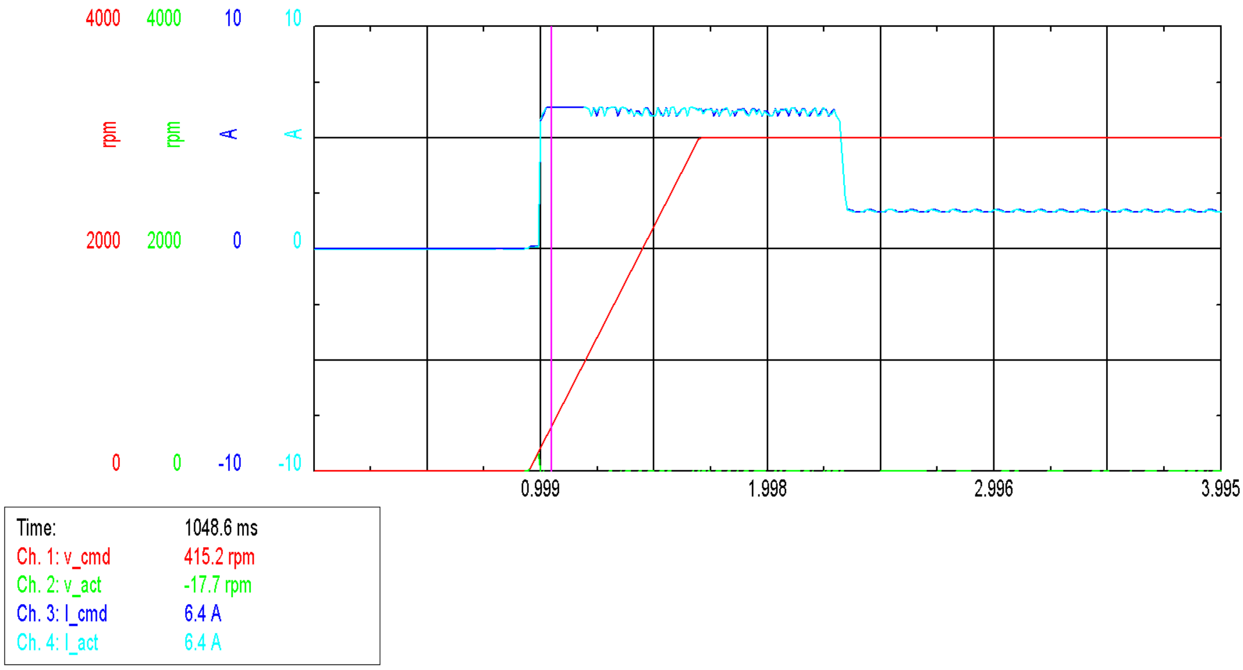


Figure 0.13: Velocity and curent responses with GVTN = 6ms

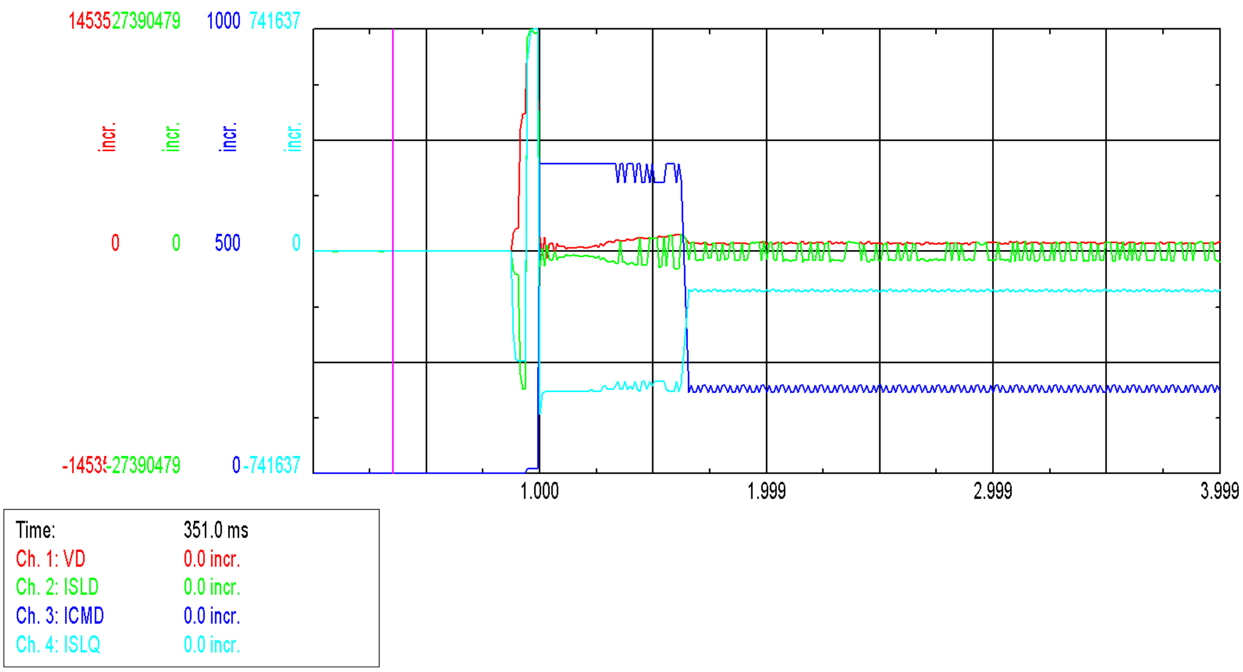


Figure 0.14: Sensorless variables with GVTN = 6ms

GVTN is on the limits

Using the parameters of Table 0.2, but GVTN = 31.5ms. Setting a velocity reference of 3000 rpm

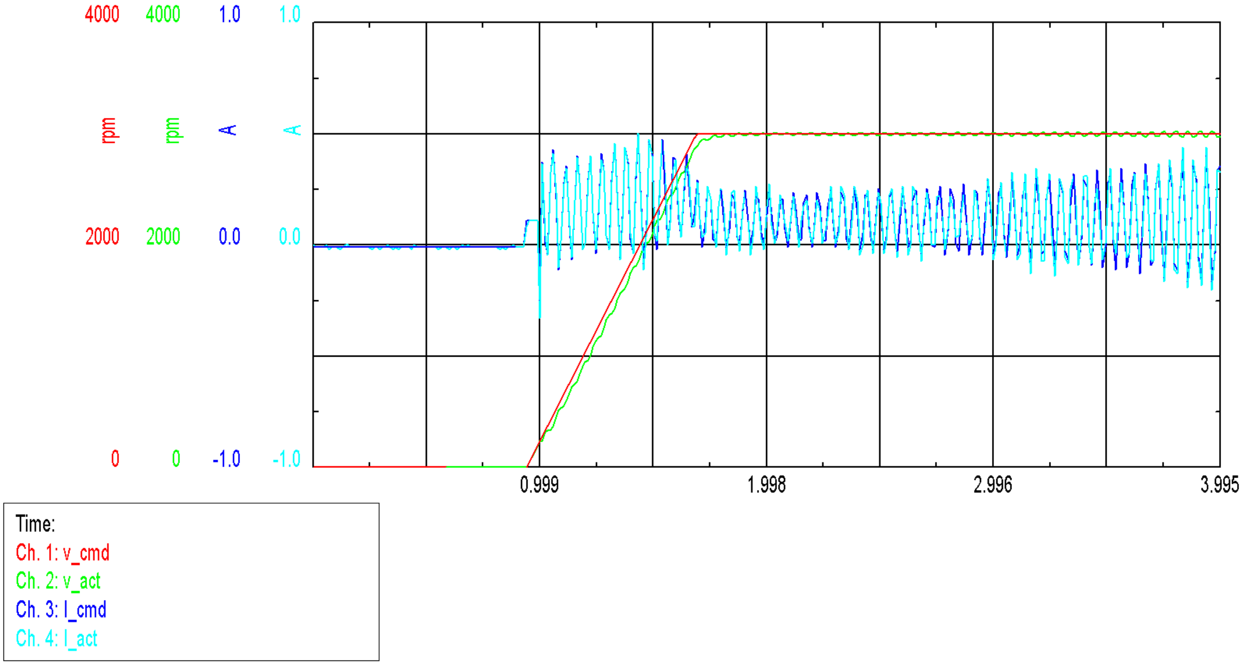


Figure 0.15: Velocity and current responses with GVTN = 31.5ms

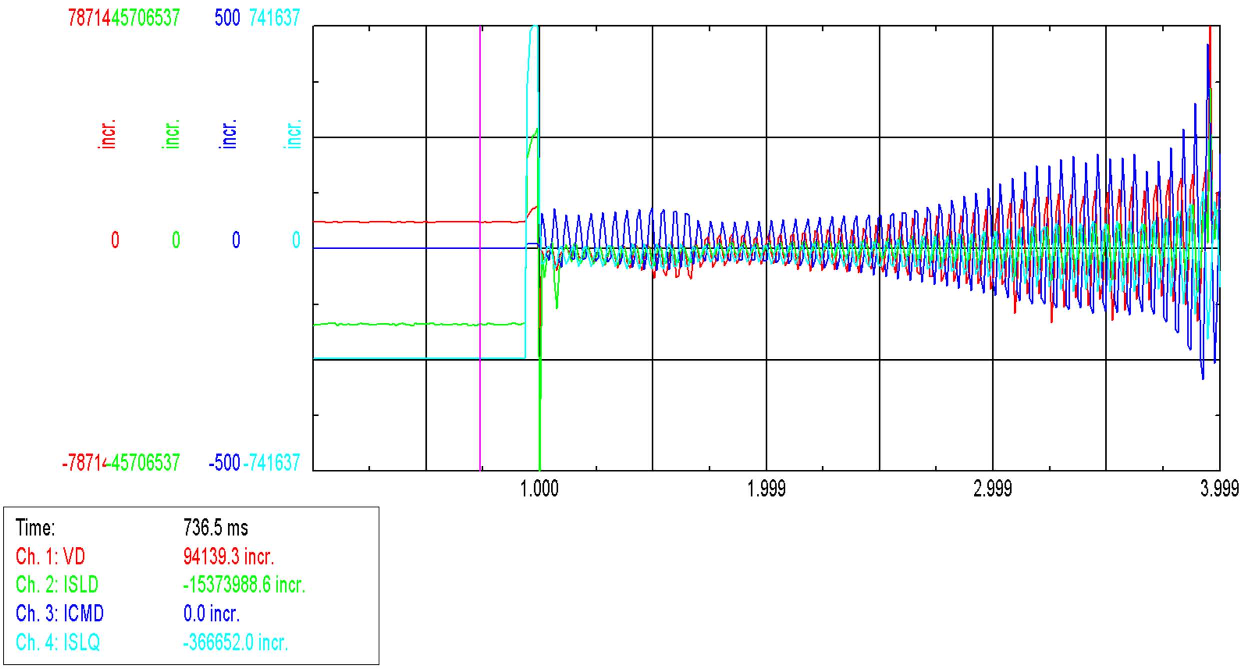


Figure 0.16: Velocity response with GVTN = 31.5ms

There is a range of values for GVTN that is on the limits between functional and nonfunctional. In such cases (see Figs. 0.15 - 0.16), the position and velocity will be correctly calculated for some instants and then sensorless get into an oscillation zone and the motor will start to vibrate and eventually lose orientation completely. As mentioned GVTN can be set to 100ms and then start decreasing this value until an acceptable performance is found.

SLIDK01 smaller than 0.2

Using the parameters of Table 0.2, but SLIDK01 = 0.06 and setting a velocity reference of 3000 rpm.

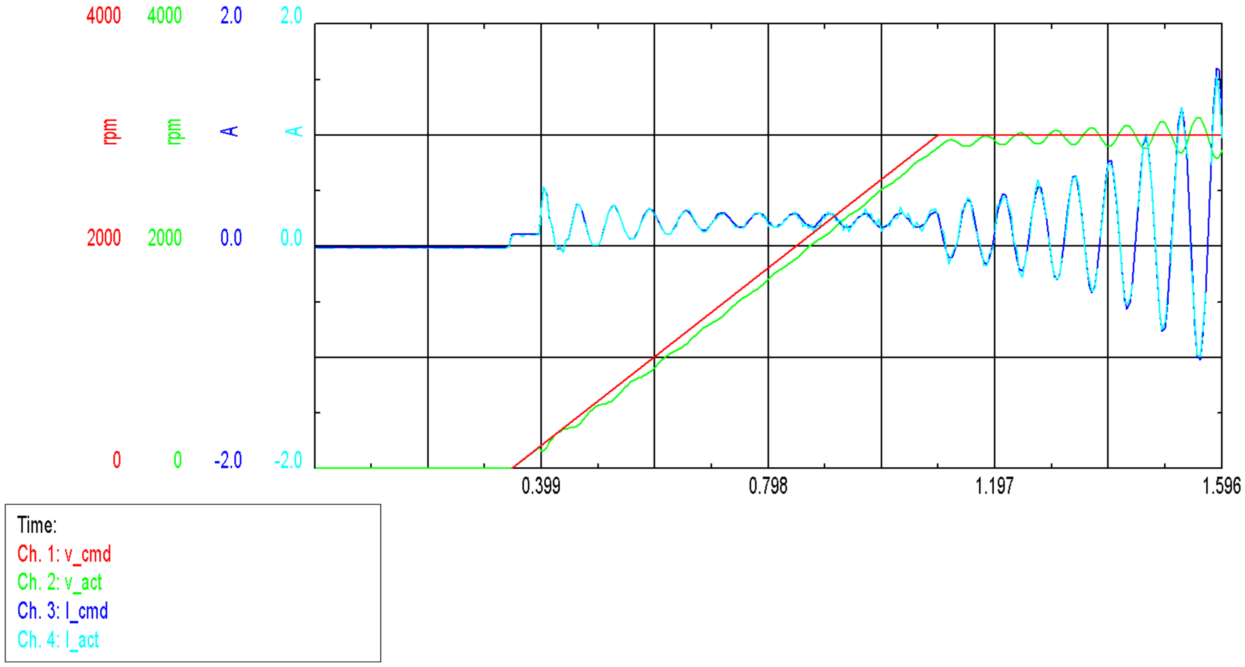


Figure 0.17: Velocity response and current responses with GVTN = 0.06ms

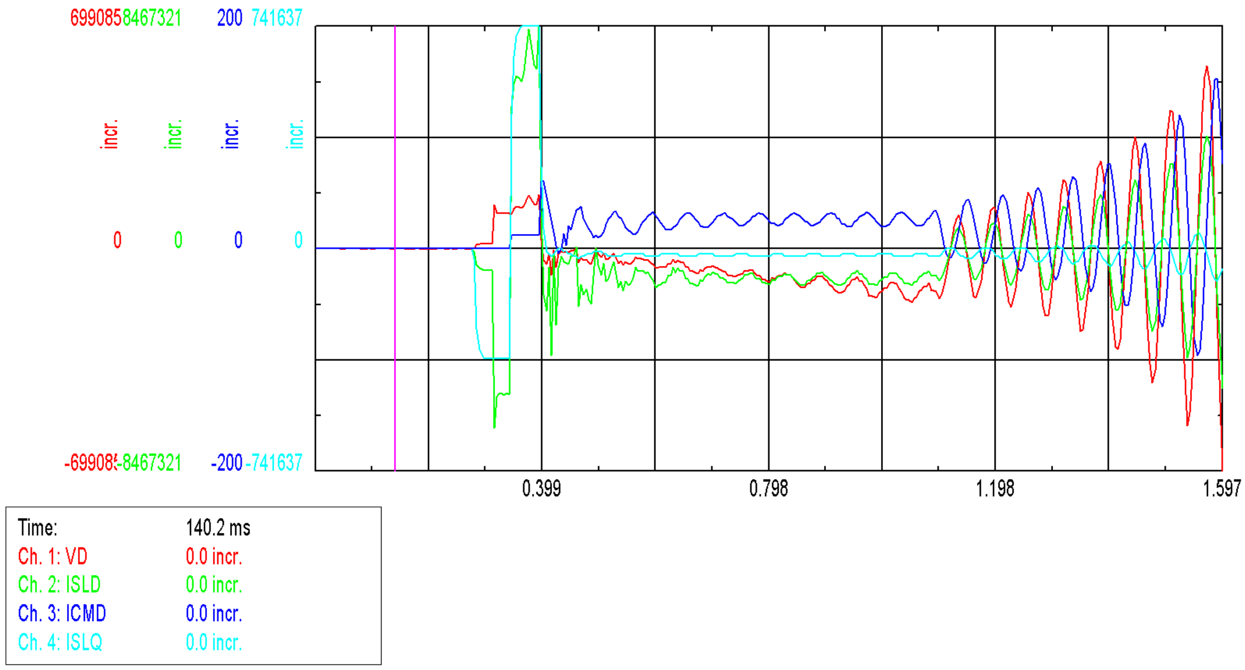


Figure 0.18: Velocity response with GVTN = 0.06ms

Figs. 0.17 - 0.18 show a similar performance as Figs. 0.15 - 0.16. Also here, the estimated actual velocity is correctly estimated, but the control gets into an oscillation zone and the motor vibrates. Differently to Figs. 0.17 - 0.18 is that here, in most of the cases, after some second the motor will remain still because the current is zero. This means the orientation has been lost.

SLIDK01 bigger than 0.3

Using the parameters of Table 0.2, but SLIDK01 = 0.4. Setting a velocity reference of 3000 rpm.

As seen in Figs. 0.19 - 0.20, the motor remains still. At the transition point DELTAERR is composed 98% by ISLD and only 2% by ISLQ. Therefore, a relative correct value for SLIDK01 is mandatory. In this case, reducing to SLIDK01 solve the problem.

As seen in Figs. 0.13 - 0.20, a wrong value for GVTN or SLIDK01 show similar troubles. A recommendation is to set firstly GVTN = 100 ms and the set a reliable value for SLIDK01. After that, you can start reducing the value for GVTN.

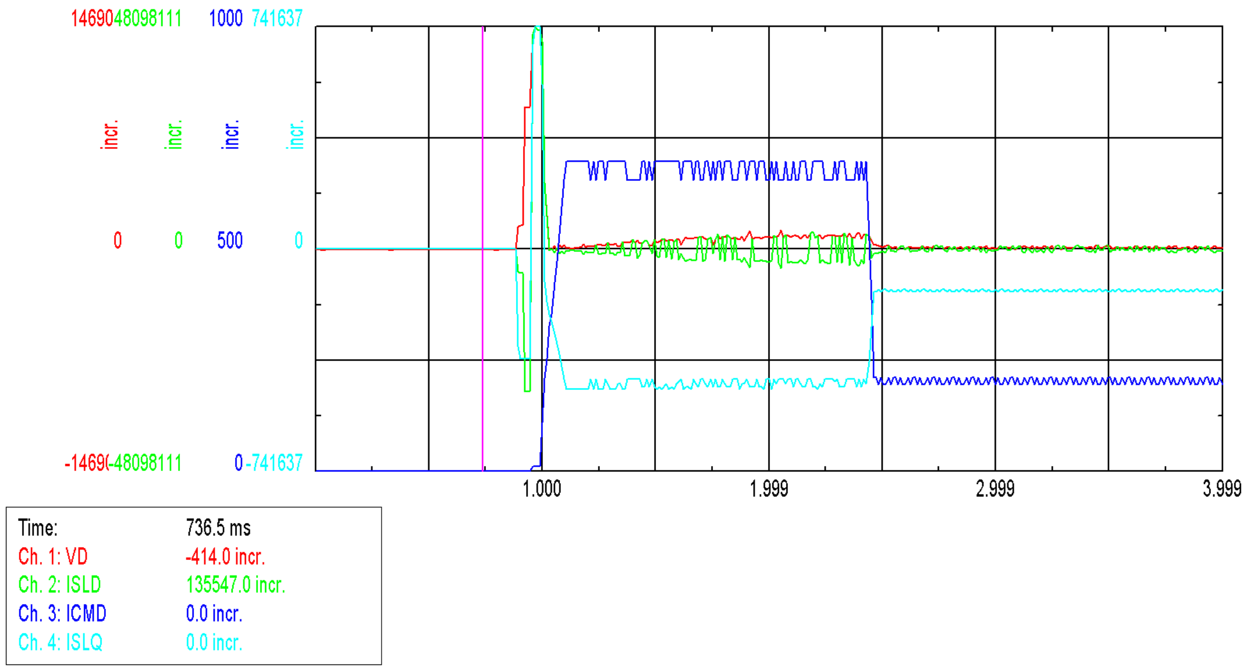


Figure 0.19: Velocity response

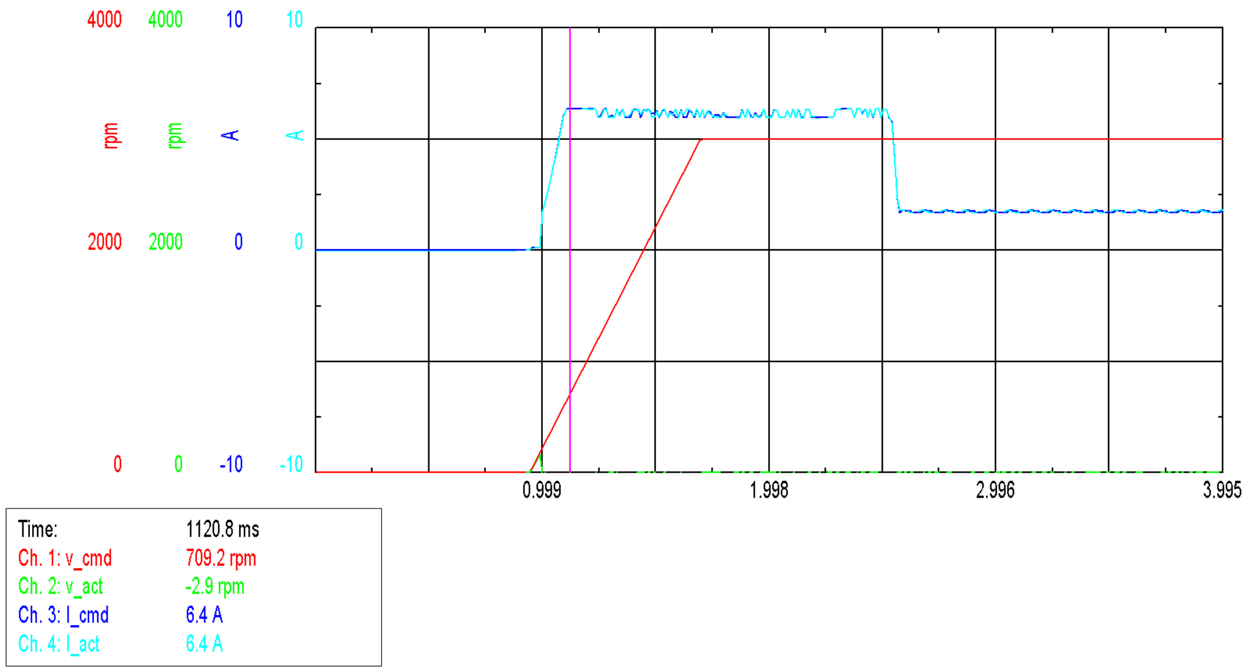


Figure 0.20: Velocity response