Electric Shaft with Digital Frequency – Comparison of i950 and 9400

Contents

1 Introduction

Lenze provides special expansion modules for reference frequency transmission. This report examines and compares the digital frequency modules of the 9400 and i950 series.

In addition, the corresponding “Electronic Gearbox” technology application for both drives is compared. Furthermore, the study examines the delay times that occur when transmitting a reference value from the master to the slave.

The goal of the tests is to examine the features, differences, and performance data of the Lenze digital frequency modules. The aim is to determine reference values for dead-time compensation for both the 9400 and i950 drives.

2 Technical Data

The synchronous test bench is used to conduct the tests (see Figure 1). The components used in the tests are listed in the following table.

Table1- Components Description

Tools/Devices	Software/Firmware Version	Device Description
i950	V1.14.1.3628	3 drives (Lenze)
3200 C	V3.20.1.4	1 controller (Lenze)
9400 HighLine	V15	2 drives (Lenze)
EK 1101	EtherCAT coupler	Manufacturer: Beckhoff
EL 5101	Incremental Encoder Interface	Manufacturer: Beckhoff
Motors	MCS 09L51 (1321) (Encoder: Am1024-8V-H)	2 motors (Lenze)
Rotary encoder	WDG 58-H	Manufacturer: Wachendorff
PLC Designer	V4.1.0	Master+Slaves i950
PLC Designer	V3.28.0	Test Program (Controller)
Engineer	V2.34	Master+Slaves 9400

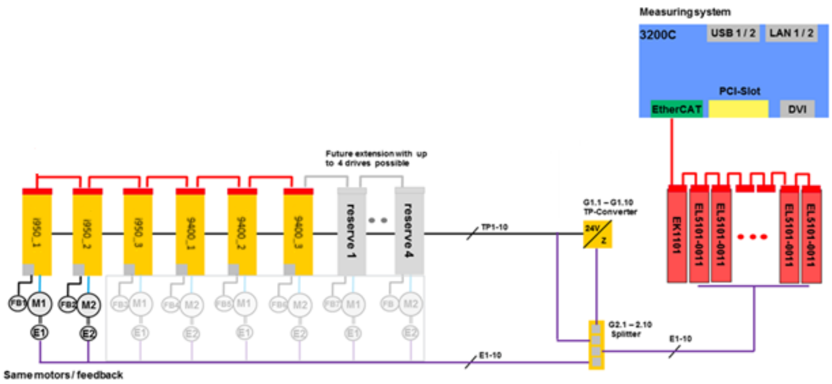

Figure1- Measurement Setup

2.1 Comparison

2.1.1 TA Electronic Gearbox 9400 vs. TA Electronic Gearbox i950

The TA Electronic Gearbox is used in the 9400 for conducting the tests. A comparable TA "Electronic Gearbox" is available for the i950, which is also used for these tests. The features of these TA units are presented below.

Table2– TA Comparison

feature	9400	i950
Operation and Configuration	Engineer	Easy Starter
Modification	FB Editor	PLC Designer
Virtual Master	Yes	Yes
Communication (Drive-to-Drive)	CAN bus	On-Board EtherCAT
Control signals	Configurable via parameters (Boolean, 16+32 bits)	Fixed at 32 bits by TA
Status signals	Configurable via parameters (Boolean, 16+32-bit)	Fixed at 32 bits by the TA

The function block configuration of the 9400 is edited using the FB Editor. Please note that when the FB Editor is enabled, the TA-specific dialogs are no longer available.

2.1.2 LF Modules: 9400 vs. i950

The digital frequency module can be installed in the 9400 in slot MXI 1 or MXI 2. The i950's LF module is installed in slot B. The following table compares the 9400 module with the i950 module.

Table3- Comparison of LF Modules

	9400		i950	
Pilot Frequency Range	Input	0.0 ... 500.0 kHz	Input	0.0 ... 10.0 MHz
	Output	0.0 ... 500.0 kHz	Output	0.0 ... 2.0 MHz
degree of protection	IP20		IP20	
Cable	Type: EYD		Type: EYD	
Connection type	Sub-D connector for LFin and LFout		Sub-D connector for LFin and LFout	
	X9:	Digital frequency input, 9-pole Sub-D connector	X6.1:	Digital frequency input, 9-pole Sub-D connector
	X10:	Digital frequency output, 9-pole Sub-D socket	X6.2:	Digital frequency output, 9-pole Sub-D socket
Encoder Type	TTL encoder		TTL encoder	
Incremental encoder signal	Two 5V signals offset by 90°		2 5V signals offset by 90°	
Sequential connections (parallel)	3 drives		1 drive	
Sequential connections (in series)	at 250.0 kHz: 20 drives at 500.0 kHz: 10 drives		at 250.0 kHz: 20 drives at 500.0 kHz: 10 drives	
Max. cable length between two devices	50 meters		50 meters	
Pin assignment for DFin			see 9400 Regarding Pin 4: Max. control range 5...12 V	

X9	Pin	Bezeichnung	Erläuterung
5 9 1 6	1	B	TTL-Eingangssignal vom Encoder oder Encodernachbildung
	2	$\overline{A}$	
	3	A	
	4	+5 V	geregelte Spannungsversorgung für Encoder (Pin 8 = Sense muss verwendet werden, max. Regelbereich 5 ... 9 V)
	5	GND	-
	6	$\overline{Z}$	TTL-Eingangssignal vom Encoder oder Encodernachbildung
	7	Z	
	8	• S • Lc • E	Die Funktion dieser Leitung muss im Grundgerät eingestellt werden: • **Sense** (Fühlerleitung bei Spannungsregelung, **Lenze-Einstellung**) • Lamp control • Enable
SUBD09010	9	$\overline{B}$	TTL-Eingangssignal vom Encoder oder Encodernachbildung

<table>
<tr>
<td>Pin Assignment DFout</td>
<td>
<table>
<tr><th>X10</th><th>Pin</th><th>Bezeichnung</th><th>Erläuterung</th></tr>
<tr><td rowspan="9">
SUBD09010</td><td>1</td><td>B</td><td rowspan="3">TTL-Ausgangssignal vom Encoder oder Encodernachbildung
Ausgangsstrom: maximal 20 mA je Kanal</td></tr>
<tr><td>2</td><td>$\overline{A}$</td></tr>
<tr><td>3</td><td>A</td></tr>
<tr><td>4</td><td>+5 V</td><td>V_{CC} ±6 %</td></tr>
<tr><td>5</td><td>GND</td><td>-</td></tr>
<tr><td>6</td><td>$\overline{Z}$</td><td rowspan="2">TTL-Ausgangssignal vom Encoder oder Encodernachbildung
Ausgangsstrom: maximal 20 mA je Kanal</td></tr>
<tr><td>7</td><td>Z</td></tr>
<tr><td>8</td><td>Enable</td><td>Digitales Ausgangssignal</td></tr>
<tr><td>9</td><td>$\overline{B}$</td><td>TTL-Ausgangssignal vom Encoder oder Encodernachbildung
Ausgangsstrom: maximal 20 mA je Kanal</td></tr>
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</td>
<td>see 9400</td>
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The frequency range of the i950, extended to 2 or 10 MHz, enables higher conductance resolutions. When retrofitting from the 9400 to the i950, the coupling cables can be reused since the pin assignments of the connectors are identical. In addition, a 9400 can be connected to an i950 (and vice versa) via the digital frequency module. In this case, the frequency limit must be observed (9400 = 500 kHz, i950 = 2 MHz), which must be specified in the application feedback.

2.2 Measurement Method: Signal Transmission Times

The transmission of a reference value from the master's application to the generation of the motor setpoint in the slave takes varying amounts of time depending on the device and the reference value source. If the setpoint takes effect on the motor shaft later in the slave than in the master, a speed-dependent position offset occurs. If the time is known, it can be compensated for by applying a setpoint delay in the master. The first step is therefore to determine the signal transmission time for various example master-slave topologies:

- i950 servo drive (master) + i950 (slave), synchronized via onboard EtherCAT
- 9400 servo drive (master) + 9400 (slave), synchronized via CAN bus
- 9400 servo drive (master) + i950 (slave), synchronized via OnBoard EtherCAT
- i950 servo drive (master) + 9400 (slave), synchronized via OnBoard EtherCAT

First, the operation of all components of the measurement system is initiated. During this process, the controller parameters are compared with one another and set uniformly for each configuration. The conductance source in the drive master is the virtual master. A value from the PDO/application is set as the signal source for the master's DFOUT. It is important to ensure that the settings (number of lines, frequency limit) for the master's DFOUT match the settings for the slave's DFIN.

In the i950 slave, the conductance source is set to Application Feedback (b) [1] and the signal source for DFOUT is set to Digital Frequency Output DFIN [1]. For the 9400 slave, the conductance source is set to DFin module and the conductance output is set to DF module: Conductance.

The reference profile is generated by the i950's virtual master for all configurations and for a total duration of 20 seconds.

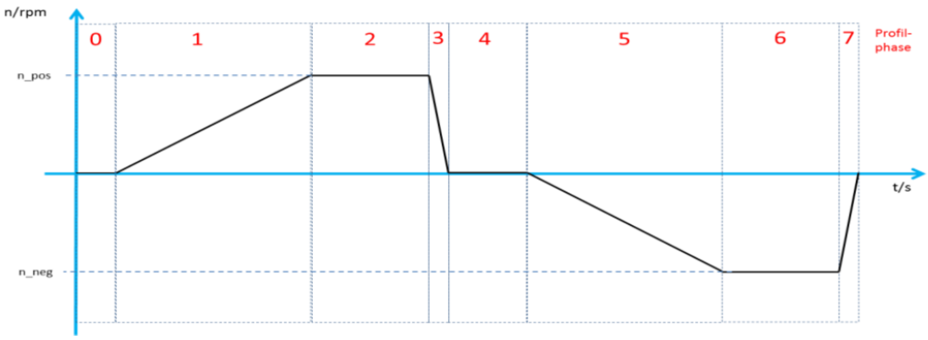

Figure2– Reference Profile

The dead times are determined during the constant-speed runs (phases 2 and 6) based on the position difference between the two motors and the average speed:

$$t_{Delay} = \frac{s_{Motor\ 1} - s_{Motor\ 2}}{\Delta v}$$

$$mit\ \Delta v = \frac{v_{Motor\ 1} + v_{Motor\ 2}}{2}$$

Here, motor 1 is assigned to the master axis and motor 2 to the slave axis.

2.2.1 Determination and Compensation of the “ ” Delay

The following propagation delays are determined for an i950 Master/Slave digital frequency network:

Table4- Delay Times for i950 Master and i950 Slave

Phase	Delay Time [ms]
2	2.63222
6	2.63158

The i950 slave follows the master position with a time offset of 2.63 ms. To eliminate this offset, the setpoint hold function in the i950’s Motion_Axis can be used on the master. This is configured via parameters 0x500A:67 and 0x500A:68. Parameter 0x500A:67 sets the compensation mode (Manual), and parameter 0x500A:68 sets the time offset to be compensated.

0x500A	67	Totzeitkompensation: Modus	Manuell (Offset in Sub 68) [3]	
0x500A	68	Totzeitkompensation: Zeit-Offset	-2.630	ms

Figure3- Parameters for Dead-Time Compensation

The effectiveness of the setpoint hold in the master becomes apparent when the time offset is recalculated with the compensation properly configured. The time offset then approaches zero, as shown in Table 5.

Table5– Delay Times After Compensation

Phase	Delay Time [ms]
2	0.00144
6	0.00284

If the i950 is replaced in the same test setup with two 9400s acting as master and slave, a delay time of 2.9125 ms is determined (see Table 6).

Table6- Latency Times for 9400 Master and 9400 Slave

Phase	Delay Time [ms]
2	2.91259
6	2.90675

A special feature of the 9400’s TA Electronic Gearbox is that two ADD blocks are already integrated into the FB Editor, which are inserted in the execution sequence before the conductance value is passed on. This compensates for a setpoint hold time of 2 milliseconds in the master. To compensate for the remaining delay of approximately 0.9 ms, the *L_SdDelayComp* block is used here in the test.

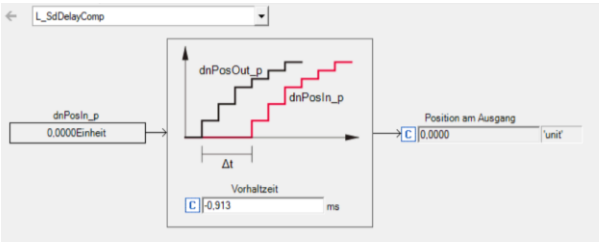

Figure4- Dead-time compensation in the 9400

In a mixed-mode operation with a 9400 master and an i950 slave, the following delay times are determined.

Table7- Delay Times for 9400 Master and i950 Slave

Phase	Delay [ms]
2	3.8472
6	3.8474

The latency for a 9400 master and an i950 slave is 3.8474 ms, making it the highest latency among all configurations.

The latency times for the i950 master and 9400 slave configuration are shown in the following table.

Table8- Latency Times for i950 Master and 9400 Slave

Phase	Latency [ms]
2	1.6929
6	1.6878

3 Conclusion

The objective of the experiments—to provide a guideline value for the necessary setpoint hold time for the various master-slave topologies—was achieved. Table 9 below shows the determined guideline values for dead-time compensation.

Table 9—Guideline Values for Delay Times

System	Delay Time Application
i950 Master – i950 Slave	2.63 ms
i950 Master – 9400 Slave	1.69 ms
9400 Master – 9400 Slave	2.91 ms
9400 Master – i950 Slave	3.84 ms

The dead time can be compensated for in the i950 master using the setpoint hold parameters 0x500A:67/68. In the 9400 acting as a master, the *L_SdDelayComp* block must be inserted in the FB Editor before the conductance value is passed on to the application in order to fully compensate for the dead time. A setpoint hold time of 2 ms—which is often sufficient—is already implemented in the FB configuration through the sequence in which the FBs are called.

For compensation in the i950, two modes are available in 0x500A:67: “Automatic for setpoints [1]” and “Manual (offset in Sub 68) [3]”. The automatic mode refers to the dead time that occurs during conductance transmission via the onboard EtherCAT system bus and is therefore unsuitable for compensating for the transmission time during digital frequency transmission.

In manual mode, the dead time is explicitly specified via 0x500A:68. If a time with a negative sign is specified, the setpoint is delayed by this amount of time. This “setpoint delay” method therefore requires parameterization in the master and applies to all slave drives in the network. Another method of compensation would be setpoint extrapolation. This can be achieved by specifying the compensation time with a positive sign. This parameterization is therefore performed in all slaves. This sign rule also applies to the 9400 in conjunction with the *L_SdDelayComp* block.

It is generally not recommended to perform dead-time compensation in the slave, as this can cause extrapolation effects that may lead to inaccuracies in the signal waveform.