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MOTOR SYNCHRONIZATION USING REAL TIME PROFINET IO CLASS1

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Abstract. *The paper presents a study of Industrial Profinet IO network and its real-time resources operating in a system that uses the synchronization of motors. For this, a pilot application was developed, based on a coil winding process of cables. A program was developed for winding of the wire in the coil, spiral form. The performance parameters: cycle time, times Response and Jitter were monitored, so that, the limits of this technology are known and reached in the equipment used. The results obtained after the data processing were satisfactory and in keeping with the expectations of this paper, and it was sought to reach the limits already presented by the company that owns the protocol and equipment, with simple equipment it was possible to reach approximate Jitter values of 10% and the Response Time below 10ms. It is concluded that these parameters have a great influence on the performance of the application and its control and fundamental for the application in the industrial environment.*

Keywords: *profinet, real time, industrial automation, coil winding process, PLC.*

1. INTRODUCTION

Many processes need motion synchronization; an example is Coil Winding Process. Transfer wires or optical fiber material to bobbins requires the coordination of rotational and translational motions (Delis, 1993). A conventional system of winding wires uses induction spindle motor, providing coil rotation, associated to precision translational movement provided by one servo based synchronous motor. Typically, material tensions limitations, synchronous acceleration and reacceleration, finishing associated processes and transients are controlled by Logical Controllers, PLC. Motor drives connected with PLC by switch and communicating in Ethernet Real Time Mode is a simple and suitable assembly to implement systems like this. The switch is the central component of a Ethernet LAN, using full duplex, Qo priority and switched communication the collision domains are eliminated and the problem of Ethernet be a probabilistic network is resolved. Several Ethernet based communication has been developed in recent years such as Ethernet/ IP, High Speed Ethernet HSE, MODBUS-TCP, EtherCAT, Profinet IO (Felser, 2005). Profinet IO provides the service definition and protocol specification for real-time communication based on Ethernet, IP, and UDP for the field area: Non-RT, based on UDP, is used only during the configuration phase; RT Class 1 can be used to communicate with standard field device. In this work the Profinet IO Industrial Network and its real-time resources operating in systems that work with the integration and synchronization between engines was studied. The authors performed a test environment to measure Cycle Time, Response Time and a Jitter on a Profinet IO network mounted with CLP ET200S and Sinamics G120 and Sinamics S120 Synchronized Motor Drivers.

2. COIL WINDING

The winding process creates a geometric structure formed by the winding of one or more wires creating one or more overlapping layers, this structure is called a coil. The transfer of the wire to the coil requires coordination of the rotational and translational movements.

Various electrical and electromagnetic applications depend on coils, such as electric motors, transformers, electromagnets, inductors and electrical resistance. These components require different sizes and shapes of reels, to be made are used reelers that perform distinct winding movements through the following techniques:

1. Flyer winding: The name of this winding technique is given by the movement that the guide tool makes, turning rapidly to for the purpose of winding the wire in the stator. The coil body is secured while the wire is driven by the rotating movement through a flyer arm around itself. This technique is mainly applied to coil rotors or high weight coil bodies such as transformer (Feldmann, et al., 2013).
2. Needle winding: The wire is wound directly into the stator grooves by radial immersion of the wire guide, depositing the wire in a vertical motion. At dead spots, where the wire is not in the upper and lower stator position, pivot movements corresponding to the winding step for depositing the wire are conducted. A tensile force is continuously applied to the wire to avoid loose windings (Feldmann, et al., 2013).
3. Linear Winding: The coil is subjected to a circular movement as the wire passes over or through a guide that runs through it axially. Due to the small inertia of the rotating mass, it is possible to achieve high speeds of rotation. The rotary movement as well as the seating movement is the main synchronization feature that will determine which winding pattern will be made. Physically large or solid coils or winding coils using very rigid winding materials are usually wound with this method. Figure 1 shows an schematic of this type of winding.

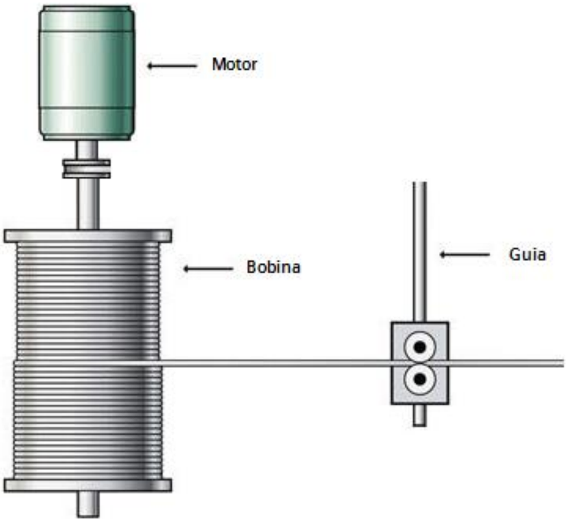

Figure 1 - Linear Winding

Another consideration that must be made is to determine which winding pattern is used. They differ by the winding technique used and the value of the fill factor achieved. In order to determine the fill factor, according to Equation (1), the number of cross sections of the wire, or number of turns multiplied by its cross section, including its insulation if present, is placed in relation to the given winding space, base and filled height in the coil. The value found must be between zero and one (Erickson & Maksimović, 2013).

$$F = \frac{d^2 \times \pi \times n}{b \times h} \quad (1)$$

Where, “F” is the fill factor, “d” is the wire diameter, “n” is the number of turns, “b” is the length of the cross-section of the coil body, “h” is the cross-sectional height of the coil body.

2.1 Helical winding

To produce the helical winding the wire crosses transversely the coil as the coil rotates. At each rotation of the coil, the yarns intersect and lie within the aperture of the layer below, since the consecutive layers have an opposite helical configuration, as seen in Figure 2

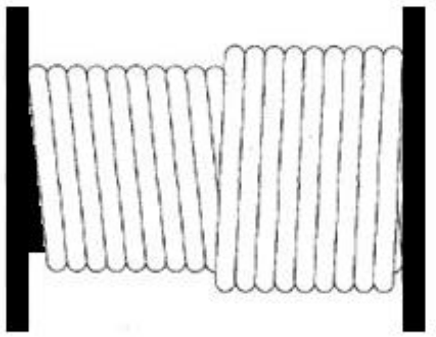

Figure 2 - Helical winding

The resulting effect is like trying to force a left-hand thread nut into a right-hand threaded screw. The yarn tries to follow the groove between two turns below it, but that groove is inclined in the opposite direction, and before a complete turn is effected, the pressure of the preceding rotations forces the yarn to jump into the adjacent groove. This process is repeated for each lap of each layer after the first. If each successive layer rests directly on the laps of the layer below it. The fill factor can reach 79% to 84%. By having a better fill factor and not having a great degree of difficulty in their manufacture, they are common in equipment that need better performance as transformers.

If the number of layers exceeds a certain limit, the structured can not be maintained and a dispersed winding is created.

3. PROFINET IO CLASS 1

Profinet is an open standard network of Industrial Ethernet for automation, standardized by PROFIBUS and PROFINET International (PI) Association. The Profinet concept has two families: Profinet CBA (Component Based Network) and Profinet IO. Profinet CBA intended for the creation of modulated plants in distributed automation, allowing a simple design of factories and production lines based on distributed intelligence, using graphical configurations between the intelligent modules. Profinet IO used for integration and data exchange between controllers and field devices. PROFINET CBA and PROFINET IO can be operated separately or in combination, so PROFINET IO device appears in the factory display as a PROFINET CBA module.

Profinet does not display hierarchy among network elements. It supports a provider/consumer model for interaction between controllers and field devices. The provider sends its data to the consumer without a request from the communication partner, so the consumer processes the data. The assignment of providers to consumers is determined in the configuration (Siemens, 2010).

The system consists of three main elements:

1. IO-Controllers; The devices responsible for configuring and parameterizing their respective associated devices and controlling the process data transfer (usually the PLC).
2. IO-Devices; The field devices like remote IO, Sensors and actuators. Cyclic data exchange between the IO Controller and an IO-Device is based on a provider / consumer model.
3. IO-Supervisor; Might be represented by the engineering station (PC or Laptop) in an installation, which has temporary access to the field devices or controller during the commissioning process.

Depending on the timing constraints, Profinet defines three types of traffic communication that best meets the needs (Ferrari, *et al.*, 2004). As shown in Table 1

Table 1 - Profinet Types of traffic

Type of traffic	Orders of magnitude	Jitter
Non Real Time (NRT)	100ms	100%
Real Time (RT Class 1)	10ms	15%
Isochronous Real Time (IRT, Class 2)	1ms	>1µs

NRT traffic typically used in specific automation tasks where time is not a critical parameter such as unit parameterization, configuration, network diagnostics (SNMP), and other IT applications handled through protocol Ethernet TCP / IP and also UDP / IP for data transfer.

RT Class 1 used in time-critical process data just like cyclical user data or event driven interrupts;

RT Class 2 performances are only possible with PROFINET IO, used for applications where response time is critical and should be less than 1 millisecond, being achieved only with hardware support in the form of a special ASIC communication that establishes Ethernet communication divided into synchronized cycles Clock.

These three types of traffic can occur simultaneously on the same physical network. Therefore, specific traffic management is required to ensure that urgent messages (i.e. those related to the two RT classes) are delivered first. This is possible because Profinet uses the VLAN (IEEE, 2006) mechanism that allows associating a priority tag with each frame.

Within PROFINET IO a time division multiplexing method is employed, the communication traffic follows the TDMA (Time Division Multiple Access) that is cyclically repeated in every network station. Dividing into three parts, Cyclic real-time data is initially transmitted, which had to be previously scheduled during the configuration phase of the system. Then non-cyclic real-time messages such as alarms and interruptions and finally the frame of the NRT messages are sent. As shown in Figure 3

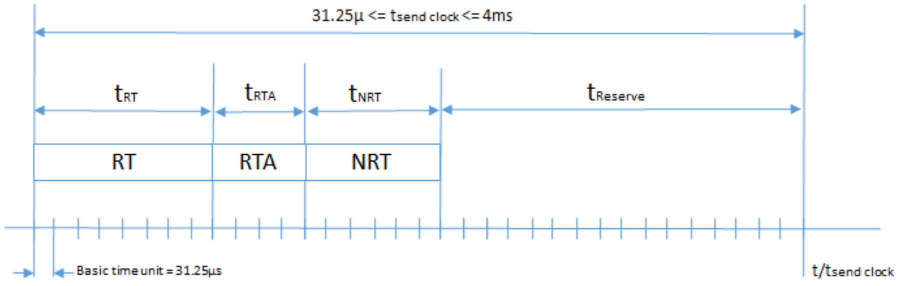

Figure 3 – Profinet IO Cycle

This cycle (Tsendclock) is subdivided into a basic time unit of 31,25µs, this unit can be multiplied by a sending clock factor between 1 and 128, so the cycle has a fixed duration between 31,25µs and 4ms. PROFINET IO RT devices cyclically transfer process data on the bus. The cycle time for real time data exchange may be different for each device. Anyhow, a device occupies the available bandwidth only for the time needed for transfer data, PROFINET IO RT specifications require that at least 40% of the bandwidth must left free of any kind of traffic, thus avoiding problems with latency and jitter. The other 60% of the bandwidth is reserved for cyclic real time (RT), acyclic real time (RTA) and non-real time (NRT) (Neumann & Pöschmann, 2005).

The transmission frequency settings may be different for the communication stations, the low performance data transmitted can use a reduction based on the sending clock time, so the slower station does not disrupt the complete data throughput. This reduction ratio had to be previously defined during the configuration phase. As shown in Figure 4

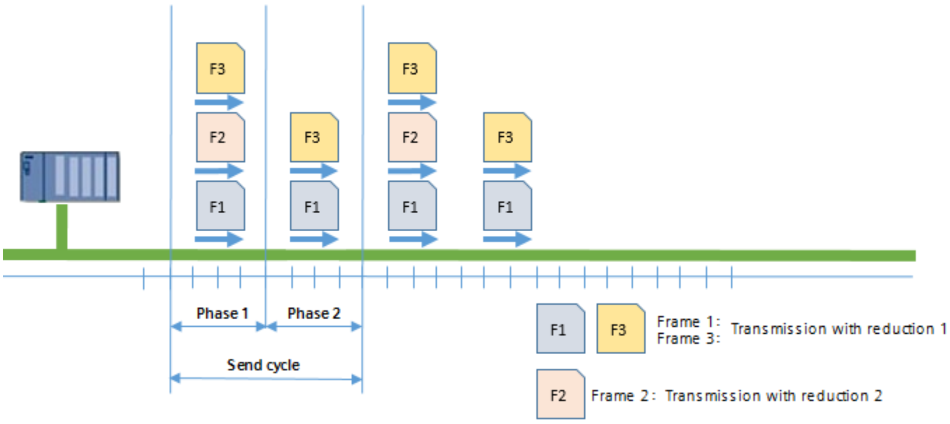

Figure 4 - Reduction cycle

Sending interval $=$ Send clock time $\times 2^n$
2^n: reduction; n: reduction ratio

PROFINET IO class 1 real-time is intended to control the bandwidth usage within the system; its network infrastructure is not critical, as long as the bandwidth is sufficiently allocated to PROFINET IO RT. It uses local non-synchronized clock programming, so the stations are not synchronized with each other, depending only on the local clock cycle of the device, so each device has a different frequency to communicate (Pigan & Metter, 2015).

Therefore, no special tolerance parameter for jitter within the system was defined, the data refresh jitter is equal to a cycle time.

4. INDICATORS AND MEASUREMENT

A network that includes real-time communication and is based on the ISO/IEC 8802-3 standard is called a Real-time Ethernet (RTE) network. Users of RTE networks have different requirements for different applications. In order to satisfy these requirements in an optimal way RTE communication networks complying with CPs described in this standard will exhibit different performance. Performance indicators (PI) shall be used to specify capabilities of an RTE end device and a RTE communication network as well as to specify requirements of an application. Performance indicators will be used as a set of interaction means between the user of the RTE CP and the manufacturer of RTE CP compliant RTE end devices and network components (Winkel, 2006).

The cycle time is the time the CPU needs to execute the cyclic program and to update the process image input and output as well as for all program parts and system activities that interrupt this cycle. (Siemens , 2016)

The cycle time starts with the operating system initiating measurement of the cycle time, and then CPU reads the status of the inputs at the input module and writes the input data to the process image input. So the CPU processes the user program, executes the instructions specified in the program and writes the states from the process image output to the output modules, ending with the operating system evaluating the determined cycle time and starting the measurement again.

The period jitter is the difference between a measured clock period and the ideal period. In real world applications, it is often difficult to quantify the ideal period, since every measurement has a little deviation. Therefore, it is usually treat the average period as the ideal period. The jitter measurement will be the peak-to-peak average over a 60s duration, over 10,000 cycles.

The response time in the case of cyclic or time-controlled program execution is the time between the detection of an input signal and the change of a connected output signal. The shortest response time is equivalent to the sum of the cycle time plus the input and output delay times, and the longest response time is equivalent to the sum of twice the cycle time plus the delay times of the inputs and outputs. The longest reaction time includes twice the update time for PROFINET IO. As shown in Figure 5

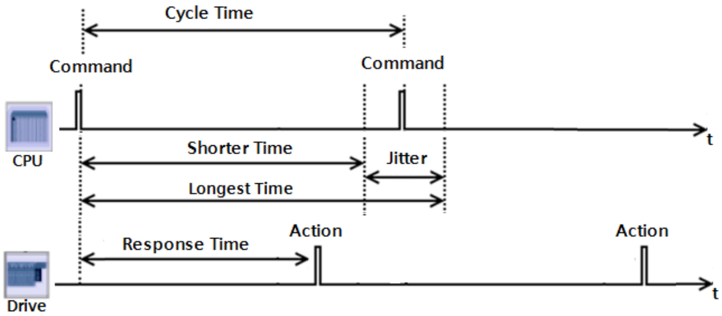

Figure 5 - Representation of cycle time, response time and jitter

5. EXPERIMENTAL PROCEDURE

The point of attention will be how to get the optimum laying on the coil winding experiment proposed, where the spindle axis is the master drive and the slave drive will be the cable guide that will move according to the rotation of the spindle. So the master drive will be set at a constant speed, when the master drive complete a round the encoder will send a pulse, this signal will be the trigger for the CLP to command the slave drive to go into motion.

The response time will be measured and analyzed by the oscilloscope connected in the computer.

The switch used is equipped with the Enable Mirroring function. Such a function can be activated through the web browser. As a result, the full Profinet IO network between the controller and the devices will be mirrored to the supervisor and can be captured by a sniffer (Wireshark). Cycle time and jitter can be measured and analyzed using the protocol samples collected by Wireshark.

The whole system will use Siemens drives according to the topology shown in the Figure 6.

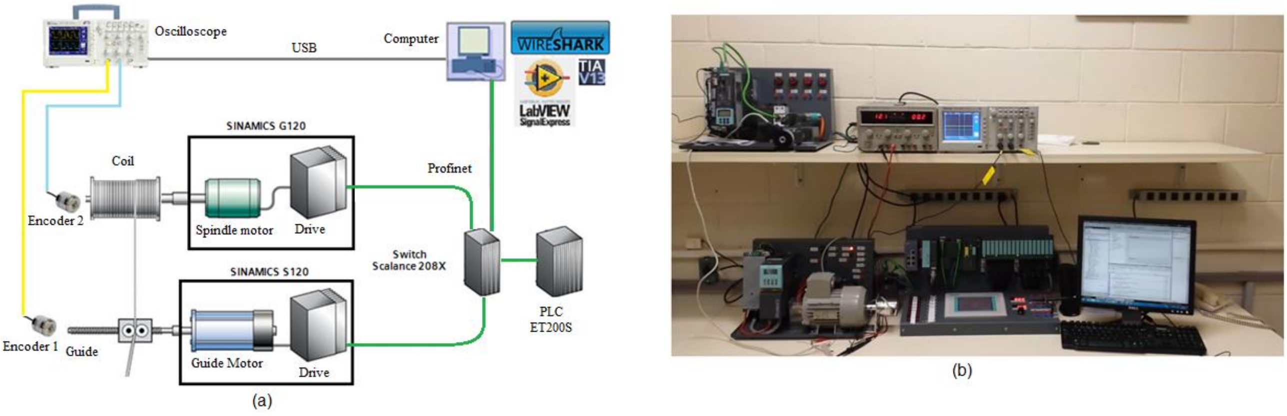

Figure 6: (a) Schematic representation of topology; (b) Assembly of the prototype

The PROFINET IO system takes the form of a star topology, a 100 Mb full duplex Ethernet network with a SCALANCE X208 (Siemens, 2013) switch. A ET200s with a 04-04 digital I/O module and High Speed Counter(HSC) module, constitutes the controller. The drives are composite by the master drive Sinamics G120 (Siemens, 2008) Inverter and the slave drive Sinamics S120 Inverter (Siemens, 2009) and a PC has been used as an IO-Supervisor. Out of the Profinet network are connected the encoders of the motors in the oscilloscope.

6. RESULTS

Data collected by Wireshark is primarily represented by histograms along with interpolation through the normal distribution of cycle times between the controller and the drives and vice versa.

The communication cycle data between the IO-Controller and the IO-Devices are demonstrated through the Figure 7, Table 2 for Sinamics G120 and Figure 8, Table 3 for Sinamics S120.

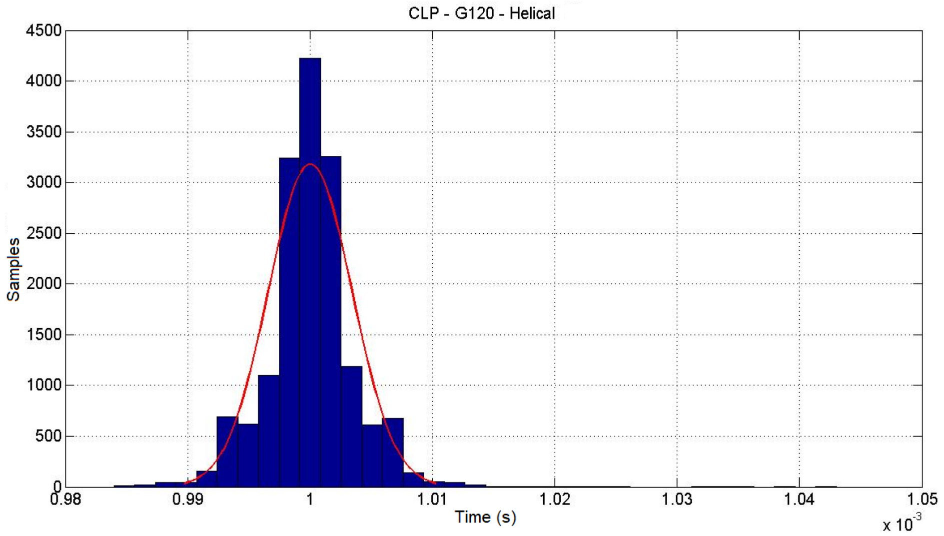

Figure 7 – Distribution of communication cycle time between PLC and G120

Table 2 - Gaussian parameters for PLC and G120

Samples	16.000
Minimum	0.984 ms
Maximum	1.043 ms
Average	1.000 ms
Standard Deviation	0.004 ms
Jitter	0.059 ms

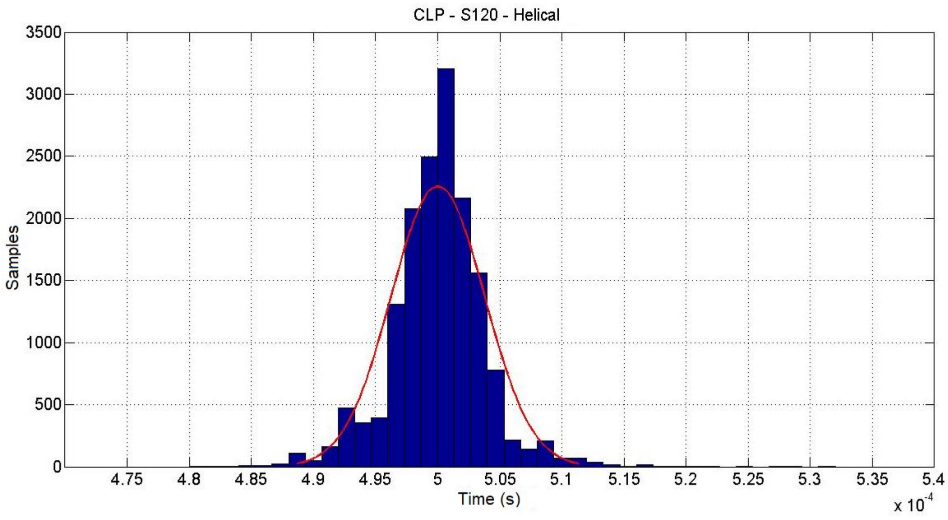

Figure 8 – Distribution of communication cycle time between PLC and S120

Table 3 - Gaussian parameters for PLC and S120

Samples	16.000
Minimum	0.480 ms
Maximum	0.532 ms
Average	0.500 ms
Standard Deviation	0.004 ms
Jitter	0.052 ms

We observed with Wireshark, that the communication cycle duration was stable with a maximum deviation of 59μs from this value.

The difference between all complete round by the Simatic G120 and the motion initiated by Sinamics S120 captured by the encoder can be seen in the graphic of the Figure 9 and the Table 4

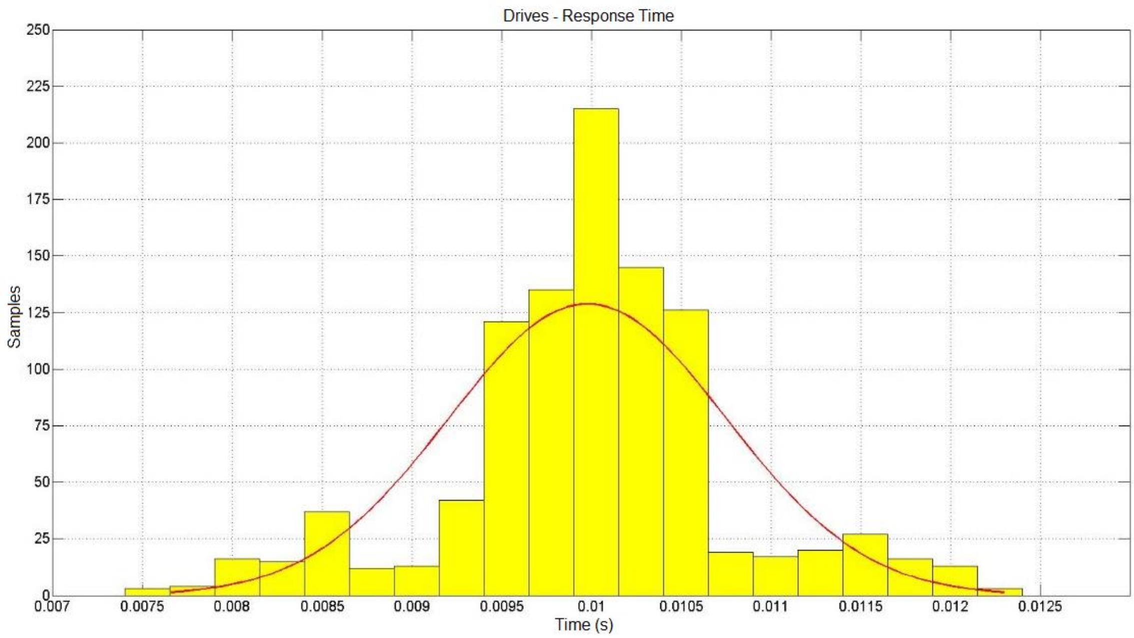

Figure 9: Response Time Sinamics G120 - Sinamics S120

Table 4 - Gaussian parameters for G120 and S120

Samples	1000
Minimum	7.400 ms
Maximum	12.400 ms
Average	9.979 ms
Standard Deviation	0.773 ms

With the rotation of 90Hz in the proposed test, the response time obtained has an average of less than 10 ms, with deviation of 0.7 ms. In the helical winding, the displacement velocity is given by v = d / T. Where d is the wire diameter, T is the lap time, for the case shown T = 11.1 ms. Assuming the process quality criterion of three standard deviations for the variation in spacing between the winding turns, in this case 2.1 ms, we will have a probability of occurrence of 0.15%, considering only the positive spacings, for an error of spacing of 18.9% in diameter.

These results demonstrate that it is possible to perfectly and accurately perform the linear winding on the helical pattern at this rotation speed of 90 Hz, or 5400 rpm, which is considered for conventional motors, based on the 60 Hz network, a high speed of rotation.

There were no significant variations in cycle times between any of the equipment. The jitter in the communications maintained values between 10.2% and 11.8% in relation to the time of the cycle.

7. CONCLUSIONS

In this work, we consider the performance of the Profinet RT communication and the results obtained show a substantial agreement between the specifications and the experimental results.

The winding process of cables requires precision in the synchronization of their axes and their productivity is directly associated to the speed of the winding. Therefore, there is a demand for the highest speed possible to obtain increase of productivity, but maintaining the quality in the winding patterns of the coils. In order to verify the limits of the protocol in the synchronization of the equipment, a prototype was created and a methodology was developed to identify these values. In this step, several network and equipment configurations were implemented in the prototype and the data collected.

The possibility of connecting all the units through the switch makes the prototype assembly very flexible and fast, in addition to a fast configuration in the Profinet system.

The first indicator, cycle time, was very stable, in no communication values were obtained outside the determined mean, 1ms for the G120 drive 0.5s for the S120 drive and the standard deviation was 4μs for both. Concluding that this indicator is not the bottleneck for the application. Still comparing the communication cycle times, it is noticed that even with different communication time values, their jitter values were very close, averaging 50 μs. Satisfactory values, since the Profinet RT communication predicts values below 15% of its cycle time

For the analysis of the second indicator, the response time, in the helical winding, the guide motor performs continuous and smooth movement. This causes the drives of the modules to have an average response time of 9.979 ms and a standard deviation of 0.773 ms between their motors when the rotation of the traction motor is at 5400 rpm

After this study it was verified that the Profinet RTE can be used for the coil winding process, since the performance indicators remained within the standards and all the synchronism and coordination of the movements were performed without the use of mechanical devices facilitating the physical assembly of the prototype.

8. ACKNOWLEDGEMENTS

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