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MOTORIZED REGULATION FOR THE SARAF PROJECT

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Abstract

Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA) is in charge of the tuning regulation systems for the SARAF-Linac project. These tuning systems will be used with Low Level Radio-Frequency (LLRF) to regulate three rebuncher cavities and HWR cavities of the four cryomodules. These systems were already tested on the Rebuncher and Equipped Cavity Test Stands (ECTS) to test respectively the warm and cold tunings. This paper describes hardware and software architectures. Both tuning systems are based on Siemens Programmable Logic Controller (PLC) and EPICS-PLC communication. Ambient temperature technology is based on SIEMENS motor controller solution whereas the cold one combines Phytron and PhyMOTION solutions.

INTRODUCTION

Context

SARAF particle accelerator is compose of elements to accelerate, control and tune a beam. To work properly, radio-frequency signals are generate by the Low Level Radio-Frequency (LLRF) system.

These signals are used in many parts of the accelerator to correct the beam. We will focus this document about two of these systems that are using motors to reach this goal: rebunchers and cavities.

First motorize tuning system is locate in the Medium Energy Beam Transfer (MEBT) line. It is part of rebunchers. Second motorize tuning system is locate inside cryomodules, next to each cavity, Fig. 1.

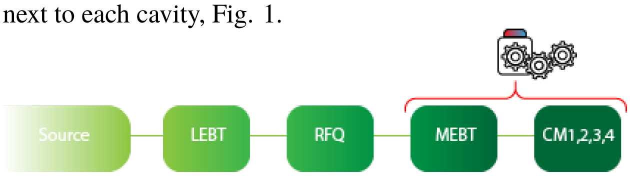

Figure 1: SARAF motors location.

Constraints

Both motorize tuning systems are working in vacuum and radiations environments due to particles accelerator requirements. A third environment parameter have to be taking account and will distinguish two motorizations systems: Temperature.

In fact, motors localize in MEBT, and so rebunchers, will be at ambient temperature therefore cavities motors will be in a cryogenic environment. We will see in next chapters that this difference will heavily impact hardware choice.

Goals

Motors have to be define by taking account of working environment but also processes requirements. In our case motors goals are similar but ways to obtain it are different.

In fact, motors have to move or apply a constraints to an element to obtain required frequency of 176 MHz. Motors movements are done according to frequency feedback measured by the LLRF. Using this feedback provide us a way to regulate movements or constraints to obtain required frequency. Rebunchers motors will linearly translate a beam-inside element to get correct frequency and cavities motors will apply mechanical constraints to cavity in order to obtain required frequency.

REBUNCHERS

Presentation

Rebunchers are dynamic tuning devices located on the MEBT section of the SARAF particle accelerator [1], Fig. 2.

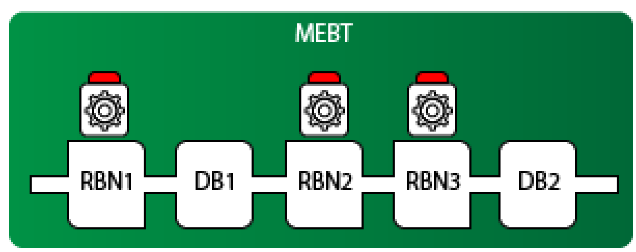

Figure 2: MEBT rebunchers.

They are three similar rebunchers, all located in the MEBT. They are composed of vacuum devices like pumps, gauges and valves but also radio-frequency parts and an outside motorization connected to an internal endless screw that movement radio-frequency passive elements near beam and so gives the possibility to modify feedback frequency.

Movement range of these elements are about thirty millimeters and require a high precision position system and without high-speed response dynamic from the system.

Hardware

According to previously mentioned requirements we will now provide details about hardware used and specifications.

Actuator Rebunchers tuning system requires a position accuracy and speed is not relevant so we choose to use a brushless motor that gives good results for this kind of use.

Moreover due to vacuum high torque requirements motors don't have internal physical brake but are using constant-current to immobilized motor's axis. In fact, motors stator

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coils are together powered with a constant power and so generate magnetic field that blocks the motor's rotor.

In addition radiations environment near particles beam impose to remove electronics from devices and so to use remote control systems. So motors are without embedded electronic and controllers will be located in remote cabinets outside radiation area, in a maintenance corridor.

Eventually SARAF control system is based on Siemens PLC and so motors are to be compliant to it. To conclude and to respond to the need we choose synchronous motors from Siemens that gives stepper functionality. This Siemens range of hardware is called as Siemens synchronous motors 1FK7, Fig. 3.

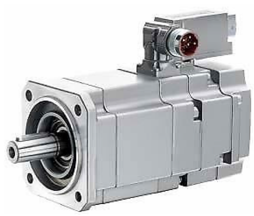

Figure 3: Siemens brushless motor.

Position Sensor Because of radiation environment opticals coders can't be use. In fact, incremental and absolute standard position encoders are using optical, and so electronic elements, not compatible with this specific environment.

A position sensor technology compliant with radiation exists: resolvers. These devices don't have embedded electronic and use coils to send impulse electrical signals to a remote acquisition system. The system will receive pulses in the same way than incremental optical coders and will be able to provide a reliable motor angle position.

Resolvers could be embedded with motors, on the rotor axis on remotely connected on a mechanical axis, Fig. 4. In our case we choose to locate the position sensor on the motor axis to have the best precision possible so it is embedded in the motor and provided as an option.

Figure 4: Siemens resolver.

Conditioning Device Resolver signals are sepcific and requires a conditioning device to convert feedbacks signals to a usable position, Fig. 5.

In fact, resolvers sensors provide three signals: A for first coil pulse, B for second coil pulse and Z or N for a reference signal. Conditioning device have to count pulse according with motor speed acquisition rate to provide position to motor controller.

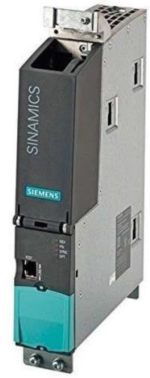

Figure 5: Resolver conditioning card.

In order to be compliant with resolver and Siemens PLC we used Sinamics sensor module.

Controller Siemens motor controler are composed of two elements: control unit to connect with PLC and power stage according to motor speed rotation and torque connected to motor itself, Fig. 6.

Figure 6: S110 motor controller.

Because we use resolver sensor only one control unit can manage feedbacks from resolver conditioning devices: Siemens S110.

Communication between motor controller and position sensor conditioning device is done with Siemens communication protocol S7. By this way, motor controller can manage motor position and correct it if necessary.

Additionally to this functionality, motor controller is connected to PLC Central Processing Unit (CPU) to receive position commands and to send feedbacks. This communication is done with another Siemens communication protocol based on a Ethernet physical layer: Profinet.

Eventually security motor movement limit switches are connected to controller front end in order to manage motor movement outside normal movement range.

PLC CPU Siemens PLC CPU used on our experiments is the 1516 and provide use the possibility to communicate with motor controller thanks to Profinet and with IOC host via TCP-IP, Fig. 7. CPU is composed of two communication cards and give the possibility to use one card per communication protocol.

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Figure 7: Siemens PLC CPU 1516.

In case of power shutdown, position of the motor is memorize in the non-volatile memory of the PLC CPU and so avoid a calibration procedure because of motor position lost.

IOC Host To communicate with EPICS PLC CPU have to be connected to an Input Output Controller (IOC). Communication is managed with TCP-IP and Modbus Protocols. IOC is host on a Industrial PC (IPC).

Global Control Architecture According to previously detailed devices we can now define the global control architecture for rebuncher motorization system.

Software

Frequency Measurement Frequency feedback used for motor position regulation is provided by the LLRF and have to be send to PLC CPU and then to motor controller.

To do it the LLRF writes the frequency value to his own IOC, then it communicates it to PLC CPU IOC that receives it and modifies position command to motor controller according to frequency dynamic.

Regulation Process Frequency regulation process is done using frequency limits. In fact, user defines positive and negative frequency limits, when these limits are reach a motor movement is done to reach frequency target of 176 MHz. Motor movement is divided in five phase: acceleration to high speed, high speed, deceleration from high to low speed, low speed and stop. Two speed profiles have be defined to optimize regulation response time. Low speed is active when measured frequency is lower than 10% of target frequency minus frequency limit. While frequency is within limits motors do not move.

This way to regulate lets the possibility to the operator to manage how precise the regulation should be and also prevents too much motors movement to avoid frequency perturbations created by fast motor movements.

Graphic User Interface EPICS control view provides frequency measurement, motor position, movement limit switches status and more.

From this view automatic frequency regulation parameters could be set, manual motor movement could be done and also motor calibration for maintenance.

CAVITY TUNING UNITS

Presentation

Cavity Tuning Units (CTU) are dynamic tuning devices located on each cavity of each cryomodule of the SARAF particle accelerator. They will be a total of twenty-seven similar systems.

Cryomodule control system manages vacuum, cryogenic, current lead and tuning systems.

Tuning systems are composed of an inside cryogenic environment motorization connected to an internal endless screw that apply a mechanical constraint on related cavity. Modify mechanical characteristic of cavity gives the possibility to modify feedback frequency.

Actuator

Cryogenic environment requires a compatible motor and it remote control. Should be added to cryogenic environment, vacuum and high radiation. To answer to these requirements we use for our experiments hardware based on space applications feedbacks.

We use Phytron stepper motors dedicated for extreme conditions, Fig. 8.


Figure 8: Phytron CSS motors.

We will detailed in next chapters how control architecture of this motor has evolved with our experiments.

Control Architecture Based on Siemens 300 PLC Generation

First control architecture was done with previous generation of Siemens PLC cards. Indeed, Phytron provides a control card named “1-STEP-Drive” that fits with Siemens ET200S remote input-output cards, Fig. 9.

This control architecture was with last generation Siemens 1516 CPU and previous generation ET200S cards. In this configuration motor did not include embedded resolver.

Control Architecture Based on Siemens 1500 PLC Generation

Second control architecture was done with last genera-tion of Siemens PLC cards. Indeed, Phytron provides a control

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Figure 9: ET200S and Phytron controller.

card named "TM StepDrive 1x24..48V/5A" that fits with Siemens ET200SP remote input-output cards, Fig. 10.

Figure 10: ET200SP control architecture.

This control architecture was with last generation Siemens 1516 CPU and last generation ET200SP cards. In this configuration motor did not include embedded resolver.

Control Architecture Based on Siemens 1500 PLC Generation with Position Feedback

This architecture is similar to previous control architecture with additional hardware. In fact motor includes embedded resolver and a fast acquisition digital input card was added on the CPU rack, Fig. 11. We could get resolver position and confirm that motor move according to positions commands.

Figure 11: Fast acquisition card.

In previous configurations we controlled motor with an open-loop control architecture but with the resolver implantation we could detect any issue thanks to a close loop. Previously the only way to detect that motor did not move even when command was send was to verify feedback frequency. It should change according to mechanical constraints on cavity, if not motor is considered as blocked.

This architecture was tested on the Equipped Cavity Test Stand (ECTS) after a motor block event due to an issue on the cavity constraints endless screw.

Control Architecture Based on PhyMOTION Control

Control architecture of Phytron motors for SARAF cryomodules is no longer based on dedicated Siemens compatible control cards but with a Phytron modular control system, Fig. 12.

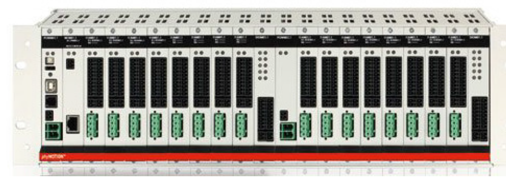

Figure 12: PhyMotion controller.

The PhyMOTION is composed of power card, communication card, like for Profinet, and control cards. We managed SARAF cryomodules PLC-based control architecture to be similar for each cryomodule. In fact one PLC CPU manage every cryomodule features for one cryomodule and we apply the same philosophy for the PhyMOTION.

Cryomodules are composed from six to seven cavities each one connected to a Phytron motor. Each cryomodule have is own PhyMOTION controller composed of motor control card, one per motor. These cards can manage motors power but also position feedback from resolver.

SARAF project strategy was not to use resolver to get a close loop regulation system but to use frequency measurement

FUTURE APPLICATIONS

Control Architecture Based on PhyMOTION Control with Position Feedback

Thanks to SARAF project feedback about PhyMOTION integration we will be able to deploy a close loop control with cryogenic motors in our next experiments.

Motor with embedded resolver will give us the possibility to improve reliability without depending of an external measurement source.

CONCLUSION

Technology for motor command and position feedback into radiation, vacuum and even cryogenic environment improves and provide use user friendly hardware and software solutions that can be connected with industrial standards.

Embedded resolver gives the possibility to have a local close loop control and improve diagnostics for non-accessible devices.

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REFERENCES

[1] Lu Zhao, "Study and test of the rebuncher for SARAF-LINAC phase 2", *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 986, p. 164716, 2021. doi:10.1016/j.nima.2020.164716