AUTOMATED HIGH-POWER CONDITIONING OF MEDICAL ACCELERATORS.

S. M. Hanna*, S. Storms, Siemens Medical Solutions USA, Inc., Oncology Care Systems Group
Concord, CA 94520, USA

Abstract

Medical accelerators require arc-free operation. Due to high-field emission, arcing and outgassing can occur in high-power accelerators. Therefore, the accelerator's inner surfaces have to be conditioned before its use at high gradient levels in Radiation Therapy machines. At Siemens, we have developed a technique to automatically condition accelerator structures by continually inspecting the accelerator running conditions (arcing and vacuum) and stepping up the pulse width, pulse repetition frequency (PRF), and RF power until reaching the maximum power rating. The implemented program also reads, displays, and archives the data it collects along the entire process of conditioning.

NEED FOR RF CONDITIONING OF MEDICAL ACCLERATORS

Uninterrupted delivery of x-ray or electron treatment requires arc-free operation of the medical accelerator. Siemens Radiation Therapy machines deliver up to 21 MeV of electron radiation and up to 23MV of x-ray radiation. Operation at such energies requires RF conditioning during the manufacturing of the accelerators structure in the factory prior to their medical use [1]. In an RF conditioning process, the pulse width, pulse repetition frequency (PRF), and peak RF power are automatically stepped up to a level higher than the maximum operational power rating [2]. This is done under the control of an optimizing technique. A Proportional, Integral, Derivative (PID) algorithm is employed where the accelerator running conditions (arcing and vacuum) are being continually inspected and the above operating parameters are changed until reaching maximum programmed power. Arcing rates and vacuum levels are decisive control variables.

MANUFACTURING WORK-FLOW AND PRODUCTIVITY REQIURMENT

At Siemens Medical Solutions USA, Inc., Oncology Care Systems Group, we have been implementing various actions and measures to streamline and optimize workflow of manufacturing and testing medical accelerators [3,4]. One process we focused on optimizing was the accelerator conditioning and testing. RF conditioning used to be carried out as part of the "Beam Test" and performed in a concrete test cell. We have designed and constructed the Accelerator Conditioning System (ACS), a separate RF conditioning process that is integrated into the accelerator manufacturing and testing workflow to increase the accelerator manufacturing capacity and productivity. As shown in Fig.1, the ACS is physically located before the concrete test cell where the "Beam Test" is conducted.

*E-mail: samy.hanna@siemens.com.

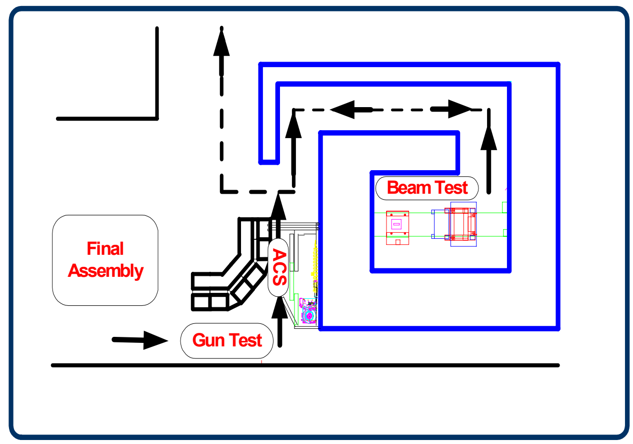

Figure 1: Accelerator Conditioning System (ACS) located within the accelerator manufacturing workflow.

ACCELERATOR CONDITIONING SYSTEM (ACS)

The main constituent sub-systems of the ACS are shown in schematically in Fig. 2. These are:

RF Source: This subsystem includes a solid-state RF driver, a 150 KV- modulator, 7 MW - klystron.

RF Transmissions Subsystem: This includes a three-port circulator, high-power water load, a directional coupler, and sampling RF probes with crystal detectors measuring reflected power.

Water Cooling System: This provides cooling to the klystron/modulator subsystem, circulator, high-power load, and the accelerator structure.

Shielding Enclosure: Lead structure was built to enclose the accelerator in order to provide the necessary x-ray shielding.

Ion-Pump: Power Supply current is measured to monitor gas activity.

Interlocks: Fifteen safety and operational interlocks to power off the system or remove triggers to the low-level drive of the klystrons.

Radiation Monitor: A calibrated radiation meter is used to monitor radiation leakage.

Computer Control: A computer program based on LabVIEW controlled the processing according to an algorithm described in the next section.

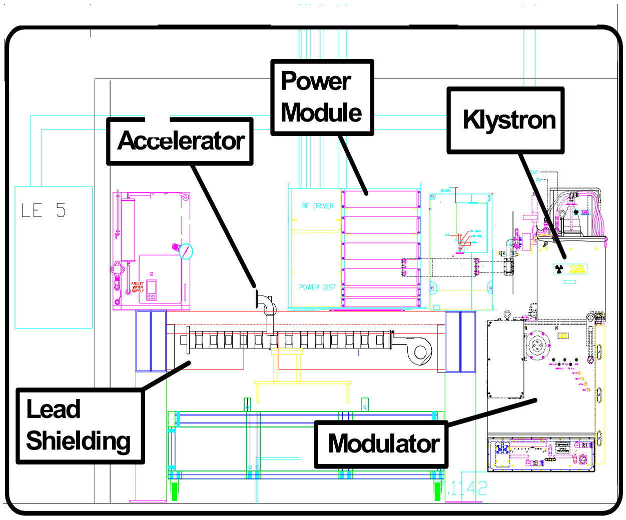

Figure 2: Layout for ACS main constituent sub-systems

ACCELERATOR CONDITIONING ALGORITHM

At Siemens Medical Solutions USA, Inc., Oncology Care Systems (OCS), we have developed a computer automated approach to condition accelerators. This process requires minimal operator oversight and both safeguards the machine and personnel against unexpected bursts of arcs and/or high ion pump currents while simultaneously acting to induce such phenomena as part of an effective conditioning process. With accurate and fast arc detection, an arcing rate can be determined and together with ion pump current monitoring a decision is made whether to continue to dwell in the Present Power Configuration (PPC) or advance. The PPC is basically the combined values of the RF peak power, pulse repletion frequency (PRF), and pulse width. Based on this, a software PID (Proportional-Integral-Derivative) controller is utilized to react to temporary high arc rates by reducing the PPC accordingly. This applies equally to the recovery of high bursts in ion pump currents, although we have found this is rarely necessary.

In addition, the algorithm provides for occasional incremental change in frequency around the nominal operating frequency of the accelerator structure during conditioning. The intentional frequency variation prevents arcs during operation as the frequency of the operating mode shifts due to heating. In the Radiation Therapy machine, an Automatic Frequency Control (AFC) continually changes the frequency of the RF source to match that of the accelerator. Fig. 4 Shows the reflected pulse for: (a) on-frequency conditioning and (b) for Off-frequency conditioning.

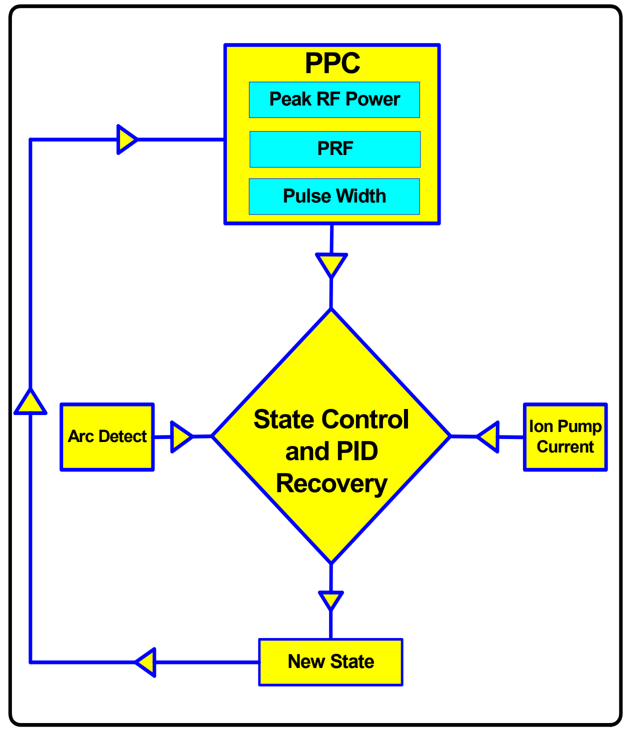

Figure 3: ACS conditioning algorithm

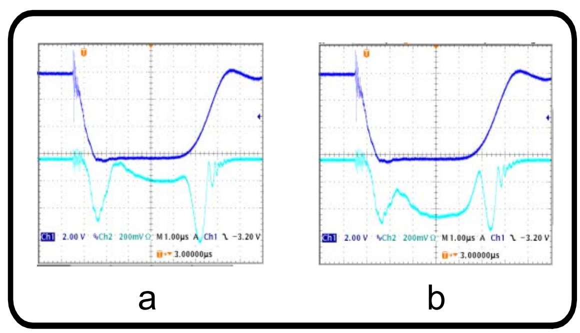

Figure 4. Accelerator reflected pulse

a) On Resonance

b) Off Resonance

USER INTERFACE

The user interface is intended to provide a maximum amount of information in a clear display form. It also allows the user to bring the system up and start conditioning with minimal effort. This is primarily done through a graphical display of normalized data, helpful in optimizing important conditioning parameters, and a state machine architecture. Additionally, separate "windows" (LABVIEW vi's) are used as a means to sort different tasks, Fig. 5. For instance, a window registry logs the accelerator type and serial number, date, operator name, etc. Another window containing the error utility allows for troubleshooting. The main running window primarily monitors system status and controls the PPC . A final report is generated and stored on disc or a server on the network for further analysis and archiving.

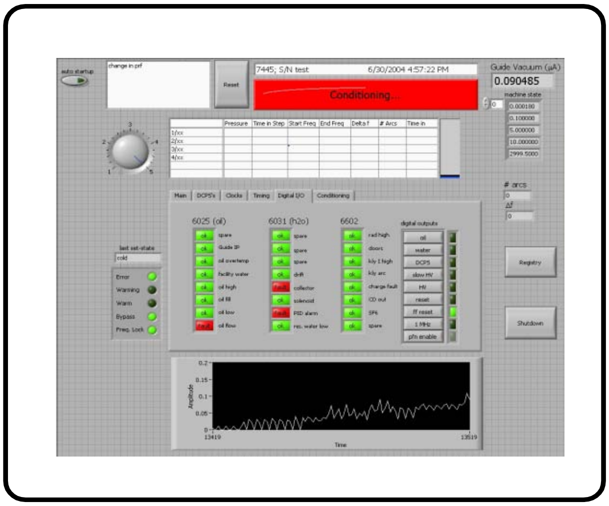

Figure 5: ACS front panel user interface.

DATA MONITORING

Quality control (QC) is an integral part of medical accelerators manufacturing. One of the means to ensure quality control is to use statistical methods. At Siemens-OCS, we have been implementing Statistical Process Control (SPC) techniques in different processes of accelerator manufacturing [2]. In our automated conditioning system, we track conditioning time, number of arcs, and vacuum level. In addition, other data is stored so that the history of a particular accelerator's conditioning performance can be retrieved as needed. Anomalous events in dwell time or arcing are noted for further analysis.

CONCLUSION

We have designed, constructed, and tested an automated RF conditioning system for medical accelerators. The approach of changing the pulse width, pulse repetition frequency (PRF), and peak RF power respectively proved effective especially in medical accelerators having relatively high-gradient field levels.

ACKNOWLEDGMENT

Thanks to Michael Riggins for his effort in design and construction. Help and support from Daniel Goldman, Everett Johnson, and David Captain is also acknowledged.

REFERENCES

[1] S .M. Hanna, et al., “Automated System for Conditioning A Linear Accelerator”, US Patent No. 6483263, Issued November 2002.
[2] V.A. Dolgashev, et al., "RF Breakdown in X-Band Waveguide”, Proc. of EPAC 2002., June 2002.
[3] S .M. Hanna, “Application Of Statistical Process Control (SPC) in The Manufacturing of Medical Accelerators”, PAC03, June 2003.
[4] S. M. Hanna, et al. "Computer-Aided Processing of Medical Accelerators," World Congress on Medical Physics (Joint AAPM and IEEE-EMB), Chicago, IL., August 2000.