Experience Operating an X-band High-Power Test Stand at CERN

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Abstract
CERN has constructed and is operating a klystron-based X-band test stand, called Xbox-1, dedicated to the high-gradient testing of prototype accelerating structures for CLIC and other applications such as FELs. The test stand has now been in operation for a year and significant progress has been made in understanding the system, improving its reliability, upgrading hardware and implementing automatic algorithms for conditioning the accelerating structures.

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INTRODUCTION

The CLIC collaboration is in the process of establishing three X-band klystron-based test stands at CERN. The primary objective of the test stands is to support the development of high-gradient, 100 MeV/m-range, accelerating structures and high-power, 50-100 MW range, rf components for the CLIC project [1]. Multiple high-power test slots are needed to test different versions of structures, different preparation techniques and to increase the number of tested structures to determine production yield.

The test stands also serve as examples of high-gradient rf systems which might be considered for a wide variety of applications including a klystron-based initial energy version of CLIC [2], X-band based XFEL linacs, high-frequency and high-gradient beam 'manipulators' such as energy spread linearizers and transverse deflectors and medical linacs. In addition, the highly flexible and highly instrumented test stands provide important data for fundamental high-gradient studies.

This report describes the configuration and first operational experience of the first of these test stands – the so-called Xbox-1. The test stand has now been operated for over a year with the main task the conditioning and operation of high-gradient CLIC prototype accelerating structures. The results of a first test are described in [3]. During this time considerable operational experience has been acquired and important control electronics and algorithms have been developed which is described in this report. The hardware set-up is described first followed by details of two crucial control algorithms which have been developed.

TEST STAND SET-UP

Xbox-1 has the classical modulator, klystron, pulse-compressor, waveguide distribution system and accelerating structure configuration similar to test stands at KEK and SLAC [4,5]. The diagnostic and control system is designed to be flexible since there are frequent changes in test stand rf hardware, configurations, diagnostics, algorithms etc. A photograph of Xbox-1 is shown in Fig. 1 and a 3-D layout in Fig.2.

Figure 1: A photograph of the Xbox-1test stand. The control and low-level rf systems are to the left, the modulator is in the middle and the high-power rf network is to the right. The test accelerating structure is located in the former CTF2 accelerator bunker located in the floor below.

Figure 2: 3D layout of modulator, klystron, pulse compressor and associated RF network.

High Power RF and Waveguide Network

The test stand comprises a 50 MW klystron/modulator unit, pulse compressor, waveguide network, structure under test and associated diagnostics. A schematic of the system is shown in Fig. 3. The klystron used is a SLAC built XL5 able to produce 50 MW of 12 GHz radiation with a pulse width and repetition rate of 1.5 µs and 50Hz respectively [6]. A Scandinova [7] solid state modulator is used as the power source. The SLEDI type rf pulse compressor, designed and built by IAP and GYCOM,

Figure 3: The high power RF schematic of the Xbox-1 test stand.

Russia, is able to compress the klystron output into a 250 ns 140MW pulse [8], enough to test two accelerating structures accounting for waveguide losses.

High vacuum WR90 waveguide makes up the rf network, except for an over-moded waveguide section which connects the pulse compressor in the gallery to the test station in the bunker. The rf valve installed in this

section ensures the waveguide network in the gallery remains under high vacuum when installing new structures in the bunker. A high power 3dB hybrid is used to split the power when testing dual feed accelerating structures. 50 dB high power directional couplers are used to send RF signals to the LLRF system for acquisition and control. Faraday cups are placed in the upstream and downstream directions along the structure's beam axis to measure dark current.

LLRF and Diagnostic Setup

The Xbox-1 LLRF system has to produce a phase modulated RF pulse and measure several different types input signals. Online signals used for interlocking and operator display are acquired by a National Instruments PXI crate, which contains 8, 250MSPS, 14-bit digitizers and a 24-channel digital multi-meter (DMM). The fast digitizers acquire log detector outputs and faraday cup signals, while the DMM records vacuum levels. An OASIS acquisition PC containing 16, 1-GSPS, 8-bit ADCs is used for acquiring the I/Q signals. These are read and archived by the PXI during breakdowns for offline analysis. As shown in Fig. 4 the PXI crate communicates via the CERN technical network with several other devices, including a VME crate, RTD reader, a PLC and the main operator PC.

Figure 4: The LLRF network, acquisition and control.

PULSE COMPRESSOR TUNING AND FEEDBACK

Due to high intrinsic Q, $>10^5$, the pulse compressor's resonant cavities are very sensitive to geometric and temperature variations and are tuned using pistons moved by stepper motors. Initial tuning was performed by the operator but caused the system to run unreliably when unmanned; a cluster of electrical breakdowns in the system would cause RF interruption hence the pulse compressor would cool down and detune.

An algorithm was written which automatically tunes the cavities to allow 24/7 operation. Fig. 5 shows how the slope of the flat top peak and the position of minimum

transmission through the pulse compressor changes as it detunes. This information is used by the algorithm to choose the tuning direction for the stepper motors. For a negative slope or early minimum both motors (one for each compressor cavity) are tuned up and vice versa for a positive slope/late minimum. This keeps the flat top slope level which in-turn reduces the peak electric field and decreases the breakdown rate. The two cavities are also tuned separately in order to keep the power reflected to the klystron at an acceptable level. This is done by measuring the energy reflected back to the klystron in the first and second parts of the reflected pulse and taking the ratio. By tuning the motors separately this ratio can be controlled and kept within safe limits (typically 2-4). Due to the implementation of the algorithm the test stand can run 24 hours a day and can recover from severe breakdown clusters.
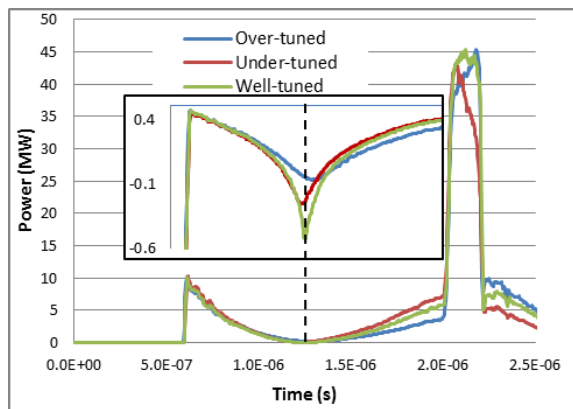
Figure 5: Typical, compressed output pulses, with an expanded view of the minimum transmission point for different tuning regimes.

STRUCTURE CONDITIONING ALGORITHM

Historically RF structures have been conditioned over time with the input power level and pulse width changed at the discretion of the machine operator. In the worst cases this can result in large increases in power and pulse width which put the structure at risk of degradation. It can also be difficult to perform or agree on a well-defined strategy for conditioning structures. Comparison of structures tested at different places and different times becomes problematic. To address all of these issues software was written to automate the process.

The conditioning algorithm has two levels of hierarchy. The first is a timed loop which increases, maintains, or decreases the power by a user-defined amount depending on the short-term behaviour of the structure (typically 2-10 minutes). This allows the power to be increased gently by tens of kilowatts every few minutes, instead of the multiple megawatt jumps every few hours/days typical of manual intervention. The second part of the software looks at the evolution of the breakdown rate (BDR) over a longer timescale (1 million pulses) and stops any power

increase if the BDR breaches a user defined value, Fig. 6. The resulting behaviour is a steady increase in power in which the BDR remains constant at a well-defined value. Results of a structure successfully conditioned with this algorithm are presented in [3].
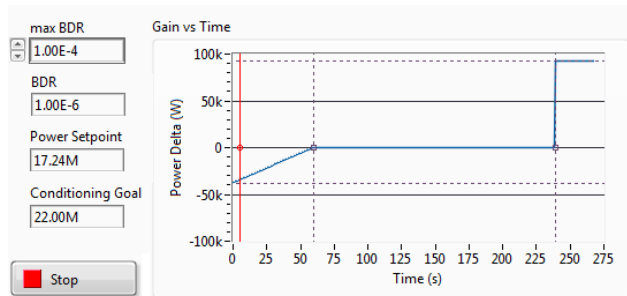

Figure 6: The GUI for the structure conditioning algorithm

CONCLUSION

Xbox-1 has been successfully commissioned and operated during tests for over a year. During this time significant progress has been made in understanding the system, and developing almost entirely computer controlled operation and conditioning-control algorithms. Xbox-1 will next be configured to allow test of an accelerating structure with beam to determine the effect of beam loading on breakdown rate [9].

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