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Automatic Conditioning of the CTF3 RF System

S. Deghaye, A. Dubrovsky[1], S. Livesley, J. Marques Balula, J. Mourier,
J-M Nonglaton, J. P. H. Sladen

CERN, Geneva, Switzerland

Abstract

The RF system of CTF3 (CLIC Test Facility 3) includes ten 35 MW to 40 MW 3 GHz klystrons and one 20 MW 1.5 GHz klystron. High power RF conditioning of the waveguide network and cavities connected to each klystron can be extremely time consuming. Because of this, a fully automatic conditioning system has been developed within a CERN JINR (Dubna) collaboration. It involves relatively minor hardware additions, most of the work being in application and front-end software. The system has already been used very successfully.

[1] JINR, Dubna, Russia

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S. Deghaye, S. Livesley, J. Marques Balula, J. Mourier, J.-M. Nonglaton, J. P. H. Sladen, CERN, Geneva, Switzerland
A. Dubrovsky, JINR, Dubna, Russia

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The RF system of CTF3 (CLIC Test Facility 3) includes ten 35 MW to 40 MW 3 GHz klystrons and one 20 MW 1.5 GHz klystron. High power RF conditioning of the waveguide network and cavities connected to each klystron can be extremely time consuming. Because of this, a fully automatic conditioning system has been developed within a CERN JINR (Dubna) collaboration. It involves relatively minor hardware additions, most of the work being in application and front-end software. The system has already been used very successfully.

INTRODUCTION

CTF3 (CLIC Test Facility 3) is currently undergoing staged construction and commissioning at CERN by an international collaboration [1]. It is designed to demonstrate key feasibility issues of the CLIC (Compact Linear Collider) scheme. It will consist of a 150 MeV linac followed by two rings for bunch-interleaving and a test stand for 30 GHz power generation. When complete, the RF power plant will consist of:

- Eleven 35 MW to 45 MW 3 GHz klystrons. One powering linac pre-buncher and buncher cavities, eight for accelerating structures, one for RF deflectors and one powering the probe beam accelerator.
- One 20 MW 1.5 GHz klystron powering an RF deflector.
- Three 35 kW 1.5 GHz travelling wave tubes each supplying a subharmonic bunching cavity.

Initially, all 3 GHz conditioning in CTF3 was done manually. This process consists of slowly increasing the RF power from the klystron as a function of parameters such as the vacuum level in the waveguides and accelerating structures, until nominal operating levels are achieved. The output power is changed by adjustment of a mechanically variable attenuator at the klystron RF input. Forward and reflected powers are observed on an oscilloscope and vacuum signals on a PC-based data acquisition system running LabVIEW installed in the klystron gallery. For a new installation or for one containing components that had not been kept under vacuum, this process could be extremely time consuming. It was therefore decided to automate it. While relatively minor hardware modifications were required, the software requirements were substantial. To be effective, it had to be written in two parts. One part containing the time-critical components had to be contained in a front-end computer incorporating fast acquisition capability. It monitors forward and reflected power and vacuum signals and reacts quickly on the klystron drive level. This part was written in C++. The second part of the conditioning programme consists of a high level cross-platform application that was written in Java. This contains the user-interface and accesses diverse equipment on a relatively slow time scale, such as the modulator.

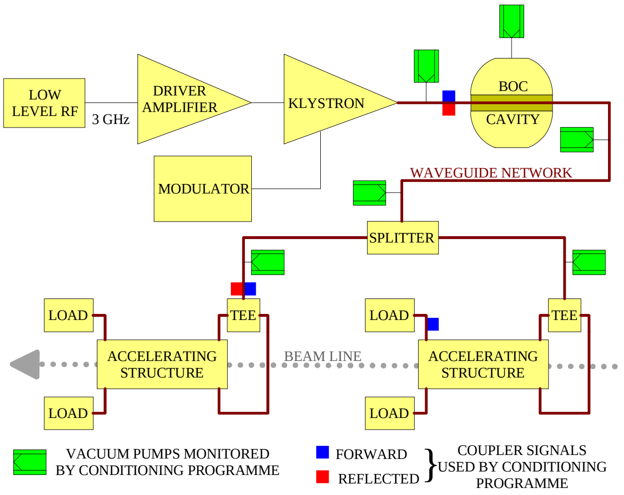

Fig. 1 Layout of 3 GHz accelerating system.

HARDWARE LAYOUT

The layout of the high power RF system for the 3 GHz accelerating structures is shown in Fig. 1. The klystron output feeds a pulse compressor that increases peak power of short pulses in excess of 100 MW. Two types are installed: LIPS and BOC [1]. The compression is controlled by a phase modulation introduced by the low level RF system. Automatic conditioning can be configured with or without pulse compression. After the compressor the waveguide network descends from the klystron gallery into the linac. The power is split to feed two travelling wave accelerating structures [1] with a nominal gradient of 7 MV/m. Klystron output power can be controlled either by drive level or modulator voltage. However the latter method is too slow to be used by an automatic conditioning programme that has to react quickly when reducing power. The driver amplifier output power could not be controlled remotely and required modification. An 8-bit DAC was added in the chassis to vary the transistor bias of the penultimate stage. A PLC module was added to control the DAC.

The high power equipment is protected by numerous hardware interlocks that are operational with and without automatic conditioning. The software thresholds for vacuum and reflected power in the automatic conditioning programme are set below the hardware interlock values to minimise the number of trips.

The FEC's (Front End Computers) in CTF3 are housed in VME chassis. The processor runs the real-time operating system LynxOS. There is one "RF" FEC for four klystrons. As well as the processor, the chassis also includes function generators for producing the compression phase function and two types of analogue acquisition cards. For each klystron there is one fast ADC card clocked at 96 MHz (5/156th of the 3 GHz). Each has eight inputs and they are used for monitoring the amplitude and phase signals taken from 60 dB couplers at various points in the high power network. There is also a slower 32-channel scanning ADC. It is used for monitoring the vacuum pumps for all four waveguide systems. The vacuum pumps and coupler amplitude signals monitored by the automatic conditioning programme are shown in Fig. 1.

As well as for CTF3's 3 GHz accelerating structure networks the automatic conditioning programme has also been configured for the 1.5 GHz deflector network that is fed by a 20 MW klystron.

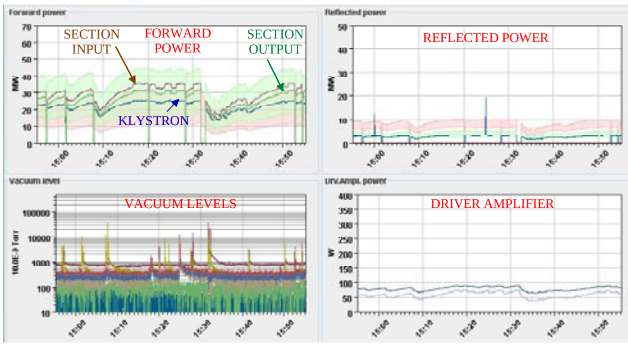

Fig. 2 User interface strip charts.

SOFTWARE

User interface

A graphical user interface permits entry of all conditioning parameters and control of programme mode. The main parameters set by the user are:

- Modulator voltage range
- Klystron forward power range
- Lower vacuum threshold above which power is no longer increased
- Upper vacuum threshold above which power is decreased
- Lower reflected power threshold above which power is no longer increased
- Upper reflected power threshold above which power is decreased
- Threshold for anomalous forward power above which power is decreased

The interface displays relevant equipment settings as well as acquired vacuum and power level data. There are strip plots of forward and reflected power, driver amplifier setting and vacuum levels (Fig. 2). Over one day's data can be stored locally. There are also plots of the acquired power waveforms. Fig. 3 shows one such plot for a shot with no compression exhibiting breakdown. Messages are constantly displayed giving the user information on the current status (e.g. power decrease due to vacuum activity, anomalous forward power, interlock, communications error).

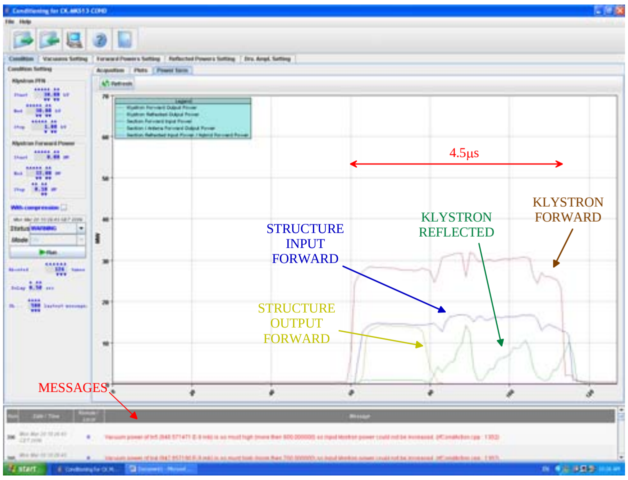

Fig. 3 User interface pulse displays.

VME data acquisition

Pulse form data acquisition is controlled by a dedicated real-time task that is triggered every 1.2 s. This corresponds to a CTF3 Basic Period [1]. During this time each channel can be acquired up to 16 times, limited by FEC memory allocation. As the repetition rate for conditioning can be set between 0.8 Hz and 50 Hz, not all pulses are acquired at the faster rates. Each acquisition contains 1024 data points, covering about 10 µs. Raw, scaled and averaged data are available both locally in the FEC and externally, principally for work-station displays. Locally, the conditioning software makes use of the scaled forward and reflected power data.

Vacuum signal acquisition in the scanning ADC is free-running and much more straightforward. Each time the conditioning software interrogates it for data, one point is obtained from each channel.

Programme structure

A simplified plan of the overall structure is shown in Fig. 4. The VME part runs in the FEC containing the RF pulse and vacuum acquisition cards and, for each klystron, only one instance of the programme is run. In contrast, several instances of the Java part can be running simultaneously. This is very useful for monitoring conditioning progress from different locations. However, only one instance is used for control of the conditioning. To facilitate synchronization in the case when several instances are running simultaneously, all the conditioning settings are placed in the front-end application and are transmitted to each Java application. All communication, whether between the two parts or with other equipment, uses CERN's CMW (Controls MiddleWare [2]) interface software. The Java application receives all data via subscription.

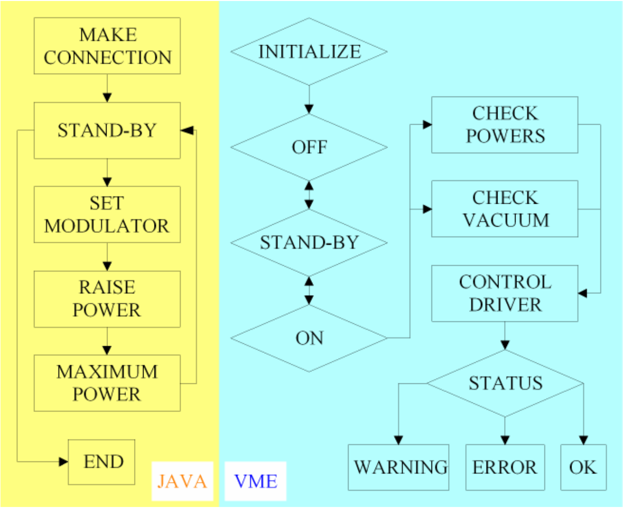

Fig. 4 Overall structure of conditioning programme.

The VME programme has been written as a FESA device [3]. It is started during crate initialisation and enters mode OFF. In this mode it simply reads power values, vacuum levels and driver amplifier setting. The Java application starts by establishing a connection to the front-end part and to the auxiliary equipment. The VME is set to STAND-BY and the driver amplifier is set to minimum. If this is successful and equipment status is normal it sets the modulator to the starting value, the VME to ON and conditioning starts. The main goal of the ON state is to be ready to increase and decrease klystron power. Power is increased if the local status is OK and the Java part gives the go-ahead. If the power needs to be decreased (vacuum activity, reflection, anomalous forward power) then the VME reacts rapidly without requiring Java involvement. It uses an empirical formula to estimate klystron output power as a function of modulator voltage and driver amplifier control setting. This way it can quickly change the driver amplifier setting. The parameters for the fit are calculated in the Java application using the L-BFGS method [4]. To check for anomalous forward power the programme compares the acquired klystron pulse to that expected from the empirical formula and from the CTF3 timing system pulse length setting. It also examines the pulse shape. The time taken by the real-time part of the conditioning programme to acquire data and perform calculations depends on whether or not new power data are available. On average the cycle is repeated every 74 ms. However control of the driver amplifier via the PLC is much slower. This operation takes about 2 s.

When maximum power is reached or when the klystron saturates, the driver amplifier is turned down, the modulator is moved to the next value and conditioning recommences. When the maximum modulator voltage and klystron power are reached the programme will continue conditioning at this level.

In the case of an error (e.g. communications problem, time-out, parameter modified externally to programme) the programme will attempt to restart. In the case of an interlock that trips the klystron the programme will also attempt to restart. However, so as to avoid multiple switch-ons and trips that could exacerbate a hardware fault, it will only do this a fixed number of times. This is set to 30 times for interlocks that cut the high voltage (e.g. reflection) and to 3 for those that also cut the klystron focus supply (e.g. klystron vacuum).

CONCLUSIONS

The automatic scheme was brought into operation in 2005 and has been used very successfully for the newly installed cavities. The programme is left to run unattended overnight avoiding many hours of tedious work in the disagreeable environment of the klystron gallery.

Much of the expertise gained with this project is now being put to use to develop an automatic system for conditioning of 30 GHz structures in CTF3. One upgrade currently under development is the integration of logging in an external data base.

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