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THE DEVELOPMENT OF THE LLRF CONTROL SYSTEM FOR THE NEW HIGH POWER TEST STAND OF COUPLERS *

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Abstract

The procedure of room-temperature high power test or condition for couplers is very import, which can hardly be circumvented before they are assembled on the accelerating cavities [1]. A new high-power test stand of fundamental mode power coupler is under development at IMP. The design, assembly and test of the RF control system has been finished up to date. This paper introduces the major functions of the LLRF control system. The test results of the arc interlock, RF test and the test of the system as a whole have been present.

INTRODUCTION

RF control system is crucial for the development of the new test stand. There are a few disadvantages for the precedent LLRF control system:

- Control devices are not compact enough.
- Remote control is not available.
- Real-time test power can't be displayed.
- The output of source signal is not precise especially in amplitude sweeping mode.

In view these shortcomings, the precedent control system can hardly meet our demand. The new control system is aimed to solve the problems just mentioned above. In addition to the conditioning modes in the old control system, including amplitude sweeping conditioning mode, pulse conditioning mode, we've embed the system with auto-conditioning mode and we've also altered the amplitude sweeping mode by adding a plateau between the "gonging up" and "gonging down" of the output power, forming trapezoid-wave in order to improve the efficiency of conditioning. Fig. 1 shows the functions we aim to accomplish in the new LLRF control system.

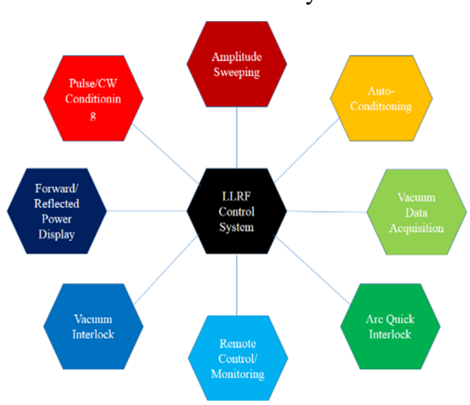

Figure 1: Layout of the functions of the new LLRF control system.

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To accomplish the desired functions, data sampling, input and output of digital and analogue signals, and fast and reliable timing are all involved. We take the product of myrio-1900(left picture in Fig. 2) produced by NI company as the core of the LLRF control system. And the whole system is developed with Labview2016. The right picture in Fig. 2 shows the new compact LLRF system.

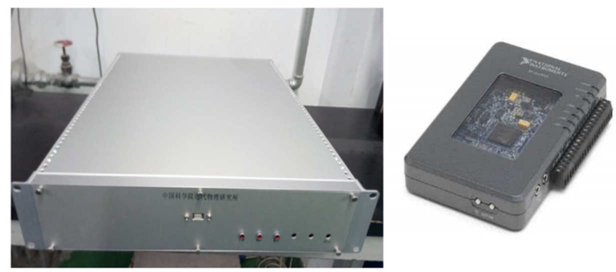

Figure 2: LLRF control system (Left) and Myrio 1900 (Right).

THE ACCOMPLISMENT OF SUNDRY CONDITIONING MODES

Pulse/CW Conditioning Mode

Practical conditioning experience has shown that conditioning in pulse mode is the most demanding step through the whole progress [2]. It's majorly because outgassing caused by multipacting is extremely serious at the beginning. Conditioning can hardly be continuous due to frequent vacuum interlocks and arc interlocks. Pulse mode in certain duty factor can make conditioning sustainable by reducing the period that multipacting lasts in the couplers, which brings less intensive outgassing. To obtain pulse signal in flexible pulse length and repetition, we utilize a fast rise (6ns) RF switch (ZYSWA-2-50DR) in Fig. 3, which has 50Ω matching resistance and is driven by TTL voltage. The pulse length can be calculated out by the PC with the input repetition frequency and duty factor, according to which the FPGA control the time that the driven TTL lasts. Because of the excellent timing of FPGA, the pulse short to 1µs can be produced.

Amplitude-Sweeping Modes

Sweeping RF amplitude is also an effective and non-dispensable way to condition couplers because of the possible recurrence of multipacting at some RF power points [2]. The precedent system can only provide triangle-wave amplitude sweeping and due to the impreciseness of timing in PC machine, amplitude-sweeping can hardly be controlled perfectly. The consequence of it is that the power nay rush

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too high, exceeding the value, especially when the ramping time is too short.

Theoretically, amplitude-sweeping is the process of regularly modulating the amplitude of RF source signal. We've accomplished such modulation with a voltage attenuator (ZX73-2500+) in Fig. 3.

As to the problem of output voltage rushing exceedingly, we've fixed it by making use of the precise timing of FPGA. Until now, ramping time can be adjusted with the range of 1ms to ∞. In order to improve the efficiency of conditioning, we've also added a plateau to the triangle wave to form trapezoid wave. The plateau time has the same range as the ramping time. Fig. 4 is the program test results with signal source. The repetition frequency and duty cycle of the pulse are 20 Hz and 1%, respectively. The envelopes might not look that neat, which is due to the test power is too low (0 dBm). The later online test results (Fig. 5) have shown that the envelopes of the amplified RF is actually much neater.

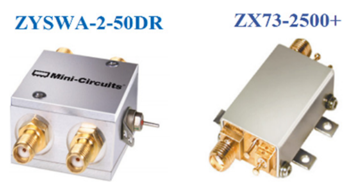

Figure 3: RF switch (Left) and voltage variable attenuator (Right).

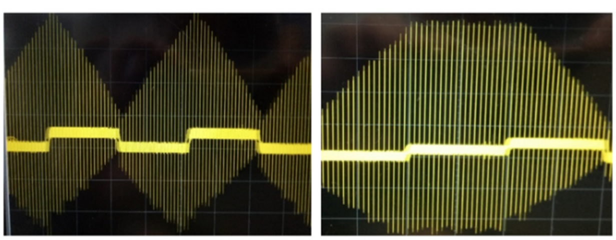

Figure 4: Output RF signal tested with signal source.

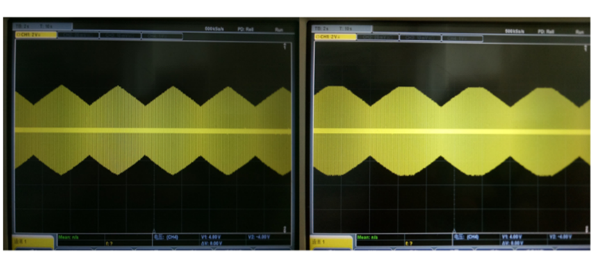

Figure 5: RF power signal picked up from directional couplers.

Auto-Conditioning Mode

To save the personnel needed to do duty work during conditioning period, we've embed auto-conditioning mode in the control system. One of the goals of conditioning is degassing the inner surface of the couplers. However, too bad vacuum brings frequent vacuum and arc interlocks. For that reason, the principle is that keep outgassing continuous but a bit moderate. Therefore, absolute vacuum data and its increasing rate are regarded as the major factors that decide what action the system should make to the controlling voltage of the attenuator. Fig. 6 is the schematic of the logic loop of the auto-conditioning mode. The actions, 'Go up', 'Go down', 'Big down', and 'Keep constant' correspond an increment, a decrement, a big slash and doing nothing to the signal source, which are accomplished solely by a voltage variable attenuator.

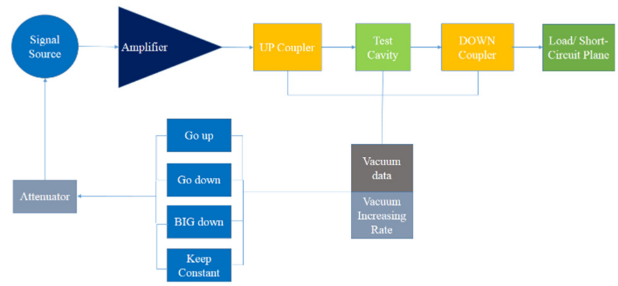

Figure 6: Logic loop of the auto-conditioning mode.

VACUUM DATA ACQUISITION

For the new designed test stand, all concerned vacuums are measured by vacuum gauges (ULVAC GI-M2). Fig. 7 shows the vacuum gauge and the accessory gauge sensor that are being in use. The vacuums can be read from the panels of the gauges. However, the vacuum data need to be input into the LLRF system for further processing. There are signal output channels on the gauges. The output signals are analogue voltage, indicting the real-time vacuum states. So long as the analogue voltage can be precisely measured, the vacuum data can be obtained through certain conversion expression. It's noted that the analogue voltage has a range of 0 to 8V, exceeding the limit (5V) of the analogue input of the myrio. So voltage divider circuits (Fig. 8 left) were added before the input channels. The plot on the right side of Fig. 8 shows the relation between the detected voltage and the vacuum data.

Figure 7: Vacuum gauge sensor (left) and ULVAC vacuum gauge (right).

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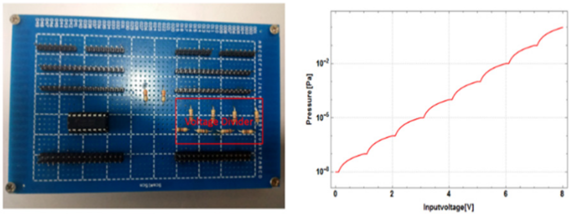

Figure 8: The front end of signals input (left) and detected voltage – vacuum curve (right).

ARC FAST INTERLOCK AND VACUUM INTERLOCK

Until now, the interlock system has comprised arc fast interlock and vacuum interlock for the time being. The overall interlock loop is described in Fig. 9. The interlock programs all run in FPGA, because of the demand of fast response.

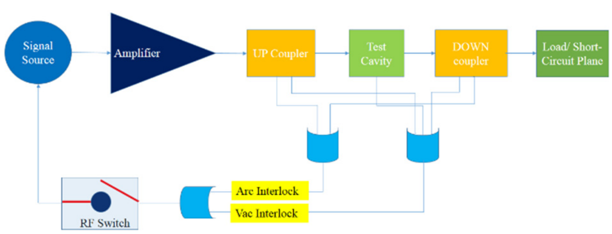

Figure 9: Overall interlock logic loop.

The test stand is designed to simultaneously condition a pair of couplers. Two arc detectors (Fig. 10) are used to monitor each couplers. Generally arc interlock need to be as fast as possible because even less then 1s of arc could make irreversible damage to the couplers. The response time of arc interlock is required to be less than 1ms. The rise time of the RF switch is around 10ns. The loop time of the FPGA protecting program is 6 ticks (150ns). And the time for reading and outputting digital signal could be neglected. Therefor the response time for the system is theoretically expected to be less than 200ns. However, the response time of the arc detector is 2μs to7μs. As a result, the minimum time it takes to switch off the RF source when arc happens in the couplers significantly depends on the response time of the arc detector (the order of microseconds). The right picture in Fig. 10 is the test result of the response time of the LLRF interlock system. The arc input signal and the switch-off output signal can hardly be resolved in time scale, but apparently the cursors indicate the delayed time is at the order of 100ns, same as the theoretical evaluation.

Figure 10: Arc detectors (left) and response-time test result (right).

The fastest sampling frequency of analogue signal input channels for our device is around 70000Hz, much slower than of digital input channels. But vacuum change is a relatively slow process when compared to arc event. Therefore, 1ms of the response time of vacuum interlock is generally considered adequate. Because we try to obtain relatively precise vacuum data, moving average is performed on the sampled input signals, thus producing longer response time. The loop time of the vacuum sampling program on FPAG is 15μs. 10-point moving average method has been taken. So the response time of the LLRF interlock system is expected at the order of 0.1ms. It's fast enough for the system to avoid precipitately outgassing.

TEST RESULTS OF LLRF CONTROL SYSTEM AS A WHOLE

In order to evaluate the new LLRF control system as a whole, we set up the test stand with the present coaxial connector and two couplers. The new test cavity is still under design by now. Fig. 11 shows the experimental setup. The setup is equipped with a 20kW solid amplifier which isn't presented.

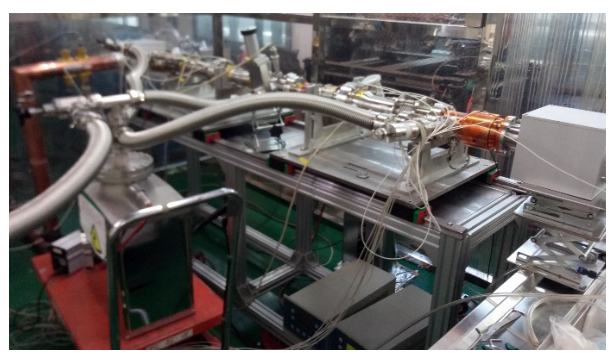

Figure 11: Setup of high power condition test stand.

Figure 12 shows the experimental results recorded by the system through 16 hours of conditioning in auto-condition mode and amplitude sweeping mode with matched load at the end of the transmission line. During the initial 9 hours, the couplers are conditioned in auto mode with the repetition frequency of 100 Hz and duty factor of 1%. In the initial stage, the vacuums are not that good (around 1×10^{-4}Pa). The threshold of triggering vacuum protection is 1×10^{-3}Pa and the increment step was set 0.001 per second for the controlling voltage signal. Over the 9 hours of automatically conditioning, nether vacuum protection nor

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arc protection happened. In the following 7 hours the conditioning mode was shift to amplitude sweeping mode with the same duty factor and a series of different frequency. And no protection event happened until the end of the 16th hour, and the vacuum went down to the order of 1×10^{-5}Pa, which is a bit better than the initial vacuum. The interlock log recorded an arc failure occurred to the coupler close to the amplifier.

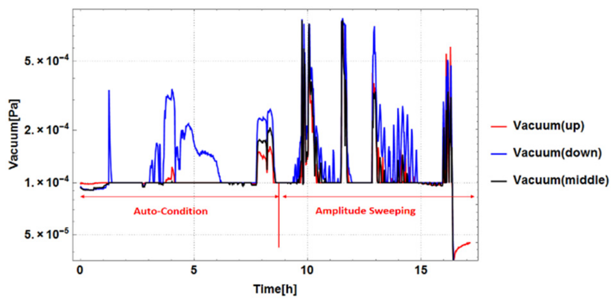

Figure 12: Vacuum variation of 16 hours of test result for LLRF control system.

CONCLUSION

The LLRF control system has a good performance judging from the present test results. The desired conditioning modes have all been tested and no bug have been found yet.

Since remote reset has already been added to the system, it won't take long to finish the next step to accomplish the function of remote control/ monitoring. The further step is to precisely monitor RF power (P_f and P_r). Possibly, temperature distribution along the pair of couplers will be monitored as well, which is also import for evaluating the real-time state of the couplers under test.

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