Conditioning of the SPring-8 Linac RF System Using Fuzzy Logic

Hironao SAKAKI, Toshihiko HORI, Hiroshi YOSHIKAWA, Shinsuke SUZUKI,
Tsutomu TANIUCHI, Atsushi KUBA, and Hideaki YOKOMIZO
JAERI-RIKEN SPring-8 project team,
Kamigori-cho, Ako-gun, Hyogo, 678-12 JAPAN

Abstract

In present accelerators it is necessary to construct advanced remote control systems. This is because the facility becomes huge and high quality beams are always specified. Under such situations the accelerator must be operated by setting precisely quantitative parameters obtained from accelerator science (quantitative control). However excellent beam characterizations are obtained not only from the quantitative control but also from the hands-on tuning provided by accelerator experts or operators (manual control). Manual control is usually qualitative and is done with uncertainty. The computer is not good at such control, so that experts or operators must aid the computer with their knowledge. If the computer system were able to embed manual control, the required beam could be obtained with much easier adjustment of the system. Such would be an Artificial Intelligence (AI) control system. At the SPring-8 Linac we have undertaken the construction of an AI system, using fuzzy logic theory. In this theory manual control is expressed by a set of linguistic rules of the form IF-THEN, plus numerical membership functions. For our first attempt we apply fuzzy logic for conditioning of the RF system. This fuzzy logic system is based on VME computers.

I. Introduction

The commissioning of the SPring-8 1 GeV injector Linac will start in August 1996. Before commissioning starts, all conditioning of Linac components will have to finish efficiently. We have designed and constructed the Linac control system [1] [2] and we are now trying to begin remote control of conditioning. Special mention should be made of the conditioning of the high voltage Radio Frequency (RF) system. Because we have chosen 80 MW klystrons, (Toshiba E3712, 2856 MHz) the RF system will have the largest average RF power in the world. The number of E3712s is 13, and we usually drive one at about ~60 MW, ~4 msec and ~60 pps. We must achieve near this power in a conditioning period from May to July 1996, a very short time. Thus, we plan that the RF conditioning will be under the AI control system, and hope to achieve a reduction in conditioning hours.

The chief problem in RF conditioning involves electric discharges, a difficult phenomenon, and best handled with the experience of experts. RF conditioning system is best directed by experience, just the situation for an AI control system. If an AI control system is adopted with fuzzy logic, then it might be able to simulate the behavior of the manual control. Thus, we shall try to control the conditioning of the RF system using the experience and sense embedded in fuzzy logic, in the hope of conditioning the RF system with high efficiency.

II. High power conditioning test of the wave guide circuit

Before design of the conditioning of the RF system using fuzzy logic simulation, the high power conditioning test of the wave guide circuit (the RF conditioning test) was carried out [3]. The test unit of a wave guide system is composed of RF windows, 3dB directional couplers, vacuum pumps and phase shifters.

The test unit is shown in Figure 1, and the RF conditioning test is summarized in Figure 2. After 420 hours a stable operation with maximum RF power (80 MW - 4 msec - 60 pps) was realized. However, this test unit does not connect to accelerator tubes. When it is, we will have longer conditioning times (500– 550 hours per one unit). We shall try to realize conditioning times of under 500 hours using fuzzy logic control. This test was very helpful in making fuzzy production rules for our AI control system.

III. Fuzzy logic system

A. Outline of fuzzy logic and the fuzzy logic engine board

The characteristics of fuzzy logic are shown in Table I, in comparison with PID (Proportional, Integral, Derivative) control. What is seen is that fuzzy logic control is good at linear and non-linear multi-parameter systems using experiential rules.

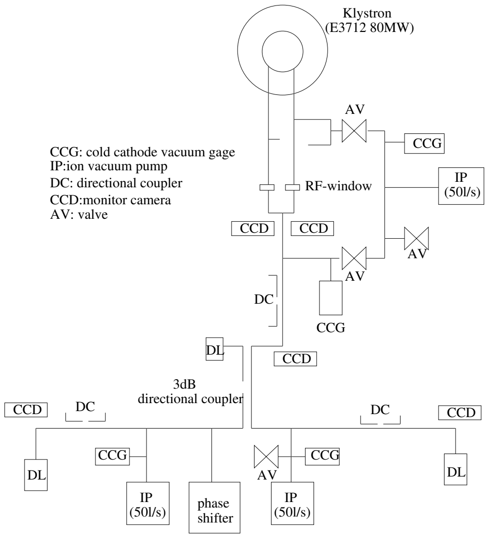

Figure. 1. High Power test bench

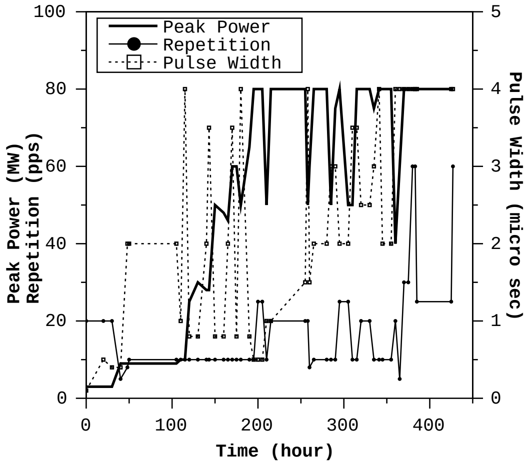

Figure. 2. Summary of the RF conditioning test

As conditioning of the RF system is quite experiential, involving avoidance of electric discharge, it is difficult to make a PID model for its control. However, we think that it is suitable for fuzzy logic control. There are some fuzzy engine boards on the VMEbus market, able to calculate fuzzy logic at high speed. We are going to adopt one, EVME-FZY21(ELNIS JAPAN), for our VME computer control system, and have already written its device drivers in C. Under fuzzy logic, a system is controlled by qualitative rules, based on linguistic and unclear values, such as “TIME = little,” where the rule parameters have no particular thresholds. The board has an easy rule editor, so that we have been able to model and set up the fuzzy production rules.

As to the fuzzy logic calculations, this board has two types of defuzzifier, a Center of Gravity (CG) method, and a Height method. Of these we have chosen the CG method for our engine. During conditioning, the system will be as shown in Figure 3.

B. Modeling of the RF conditioning

We must model the conditioning of our RF system. All of an operator’s judgments are influenced by experience in such work. First of all we state a new experiential guideline which we call “RF power safety (safety)”.

Table I
Comparison of fuzzy and PID control

characteristic	fuzzy	PID
the subject of control		
: model	unnecessity	necessity
: qualitative relation	experiential	unnecessity
operation		
: speed type	possible	possible
: positional type	possible	possible
: saturation	little	many
read a rule	good	bad
structure of control system	complex	simple
changeover control	sequence	nonsequence
knowledge control	fit	unfit
number of input, output	one or many	one set only

1. If it is zero, then the peak power agrees with the RF conditioning test value (experiential value).
2. If it is a negative large value (safety=bad), then the peak power does not agree with the experiential value, and it is above the "safety = zero" line. There is a significant possibility of electric discharge.
3. If it is a positive large value (safety=good), then the peak power does not agree with the experiential value and is under the "safety = zero" line. There is little possibility of electric discharge.

Safety is used for judgment of the RF peak power value. Figure 4 shows the judgment of RF power safety. Under this guideline, we have modeled that there is a two step judgment in the RF conditioning process.

Step 1: Safety is obtained from the results of RF conditioning tests. It requires two input variables.
 a. Time interval is small or large.
 b. Peak power is low or high.
Step 2: We judge the peak power steps according to the present safety. Three input variables are required.
 a. Safety is good or not
 b. RF pulse width is short or long
 c. Vacuum value is good or not

These variables are used to make the fuzzy production rules and membership functions. Figure 5 shows the block diagram of the RF conditioning system. The following subsection discusses in detail the construction of fuzzy production rules.

C. Fuzzy production rules and membership functions

We have made 52 rules and 6 membership functions from models of conditioning.. Generally speaking, this control systems should be designed to be fail-safe. Our high power RF system, having such a large average power, has the potential to cause severe equipment damage in the case of an accident. Figures 6 and 7 show the fuzzy production rules and membership functions created.

Each membership function has the following definition.

A) Fuzzy inference Step 1
 1. Definition of peak power and time on the RF conditioning test.
There are 5 levels for raising the peak power, 0–10 MW (0–100 hours), 30 MW (~110 hours), 50 MW (~120 hours), 60 MW (~150 hours), and 80 MW (~180 hours). These regions have greater possibility of electric discharge. Thus we must be careful in these regions not to hurry up input power increases. This is reflected in the definitions of the membership functions in these regions.
 2. The definition of safety peak power has 5 regions, so safety also has 5 regions.
As the system must be kept fail-safe, the membership function of safety leans toward the negative.

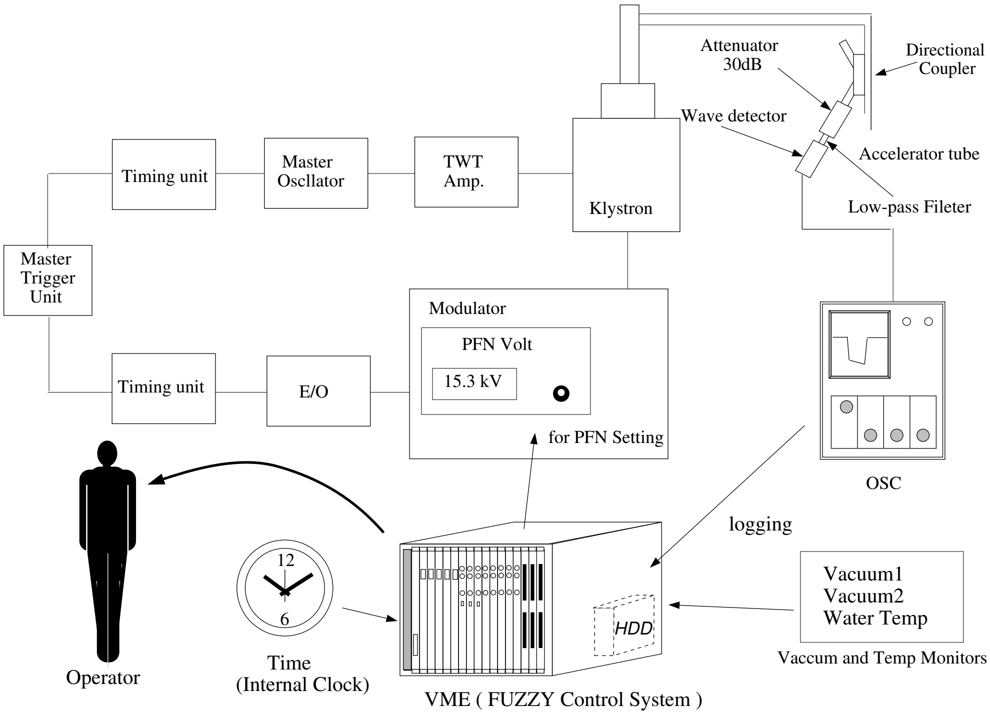

Figure. 3. Design of the conditioning system using fuzzy logic

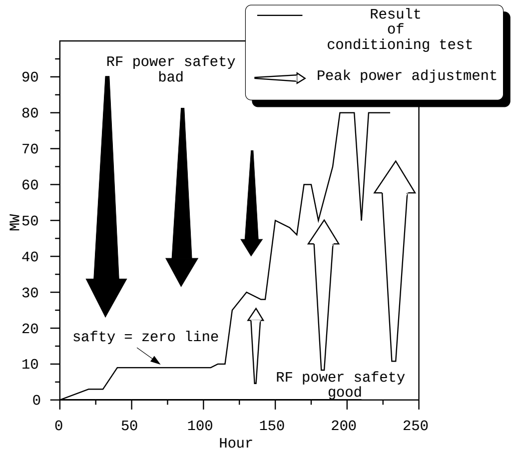

Figure. 4. Judgment of the Conditioning

B) Fuzzy inference Step 2

1. Definition of Vacuum

During RF conditioning we want to keep the vacuum value about 1–3x10^{-7} torr. The vacuum interlock set level should be ~5x10^{-7} torr.

2. Definition of Pulse Width

As pulse width increases electric discharges occur more frequently. We must be especially careful for pulses longer than 2 msec.

3. Definition of Step

Step is the control parameter of RF power adjustment. If step is positive and large, then the RF peak power is getting large. For example, if the vacuum value is getting bad then the step must get negative quickly, as we must keep the system fail-safe.

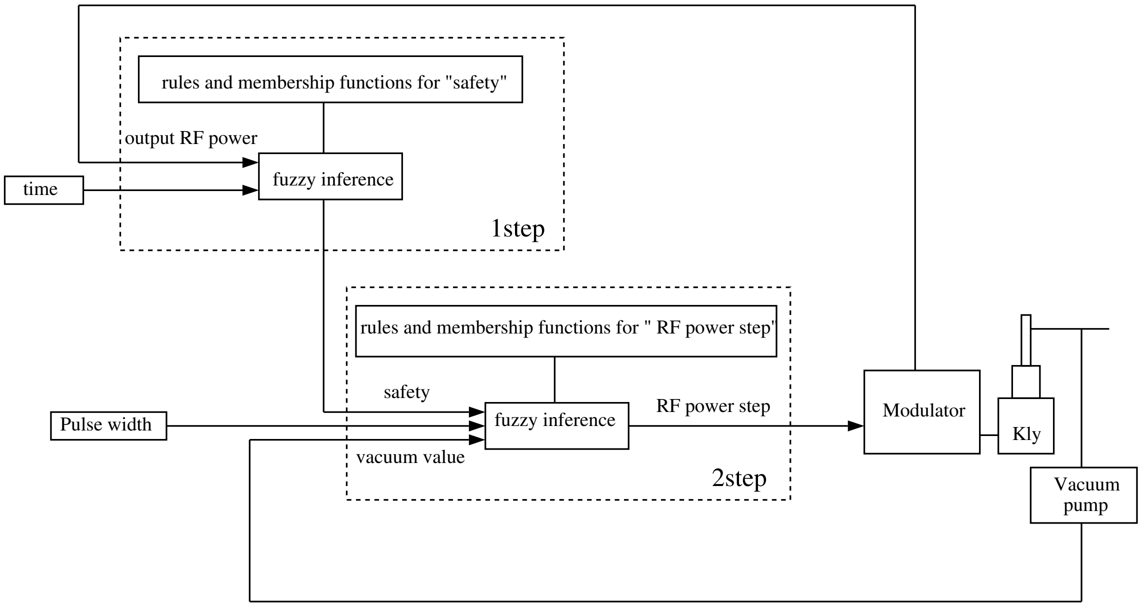

Figure. 5. Block diagram of the RF conditioning system

Table II
Result of the step2 fuzzy inference

Peak power (MW)	10	40	40	40	40	40	60	80
Time (hour)	180	180	30	180	180	180	50	200
vacuum value (x10^-10 torr)	1000	1000	1000	1000	100	4000	1000	1000
pulse width (μsec)	0.5	0.5	0.5	3	1	0.5	0.5	1
safety value	11	3	-35	3	3	3	-35	0
power step	7	5	-6	4	7	-26	-6	1

IV. Simulation

The RF conditioning was simulated using these fuzzy production rules and membership functions. Figure 8 shows the result of step 1 fuzzy inference. A simulation was performed relating passage of time and peak power. In this figure the open squares show “safety = zero” from the simulation. Using our fuzzy production rules and membership functions, the simulation is in good agreement with the RF conditioning curve. Table II shows the results of step 2 fuzzy inference. For example, if peak power is 10 MW, time is 180 hour, vacuum is 10^{-7} torr, and pulse width is 0.5 msec while the passage time is very long, then peak power is not large, so that the power steps can be given a positive large value (=7). If vacuum is too bad, ~$5x10^{-7}$ torr, the power steps are large and negative (value = -26).

As we want to have a minimal discharge system, the peak power is lowered quickly. When peak power of 80 MW is achieved, the power step is near zero. In this case the system does not require more RF power.

V. Conclusion

We have constructed and simulated an RF conditioning system using fuzzy logic. In May 1996 we will use it in production, and hope to achieve conditioning times under 500 hours. First we will do the RF conditioning test (local operation) of only one RF unit (with accelerator tubes) for recheck of the RF system. Though there may be some accidents in this checkout, the fuzzy logic control system will reflect this. In the future, the membership functions will be learned by neural control, and thus the system will become more intelligent. Later we are going to gather many fuzzy production rules on Linac operation, for example, phase control, beam energy control, etc. These rules will be managed using a

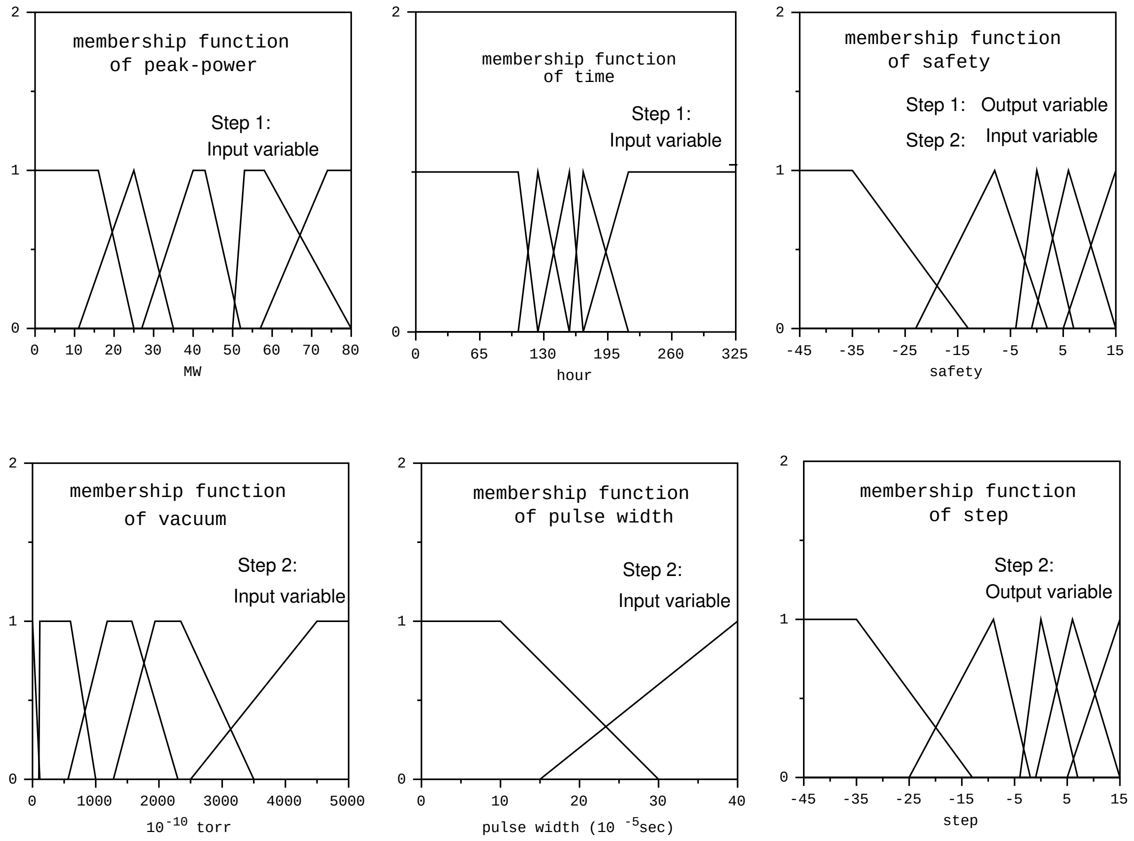

Figure. 6. Membership functions of the RF conditioning

database and employed on the AI control system.

References

[1] H.Yoshikawa et al., Nucl. Instr. and Meth. A, 352,216-217 (1994)

[2] H.Sakaki et al., Proc. of Particle Accelerator Conference and International Conference of High-energy Accelerators, Dallas, Texas USA (1995)

[3] S.Suzuki et al., Proc. of 10th Accel. sci. and Tech., Hitachinaka, Japan, Oct. 25-27, 1995, to be published.

Fuzzy inference Step 1: 25 rules

If PEAK = quite low & TIME = little then STABILITY = good
If PEAK = quite low & TIME = zero then STABILITY = positive small
If PEAK = quite low & TIME = big then STABILITY = positive big
If PEAK = quite low & TIME = quite big then STABILITY = positive big
If PEAK = quite low & TIME = too big then STABILITY = positive big
If PEAK = low & TIME = little then STABILITY = negative small
If PEAK = low & TIME = zero then STABILITY = good
:
:
If PEAK = quite high & TIME = quite big then STABILITY = good
If PEAK = quite high & TIME = too big then STABILITY = positive small

Fuzzy inference Step 2 : 27 rules

If STABILITY = negative big & VACUUM = too bad then STEP = negative big
If STABILITY = negative big & VACUUM = quite bad then STEP = negative small
If STABILITY = negative big & VACUUM = good then STEP = negative small
If STABILITY = negative big & VACUUM = quite good then STEP = good
If STABILITY = negative big & VACUUM = excellence then STEP = positive small
If STABILITY = negative small & VACUUM = too bad then STEP = negative big
:
:
If STABILITY = positive big & VACUUM = quite good then STEP = positive big
If STABILITY = positive big & VACUUM = excellence then STEP = positive big

If PULSE_WIDTH = short then STEP = positive small
If PULSE_WIDTH = wide then STEP = zero

Figure. 7. Rules of the RF conditioning

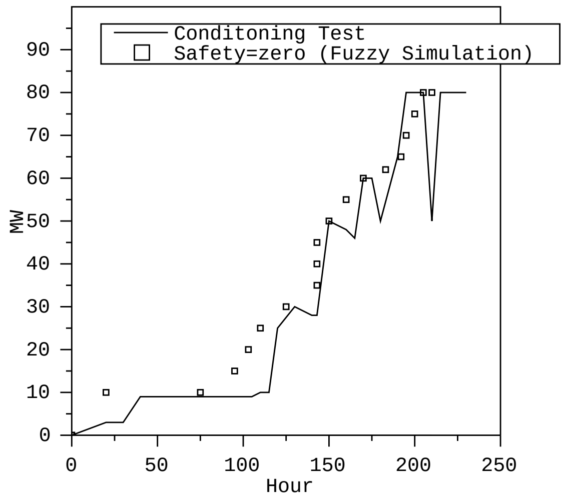

Figure. 8. Result of the step1 fuzzy inference