

THE RF FERRITE-TESTING PROGRAM AT NAL

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Summary

Investigations at NAL on ferrite disclosed a time dependent RF loss phenomenon occurring only at high power. Ferrite toroids of two manufacturers were tested to obtain enough cores of adequate power-handling capability for both the Booster and Main Accelerator cavities. The central portion of the test apparatus was a half wave coaxial cavity impedance matched to a 5kW power amplifier. The core selection criteria for Booster and Main Accelerator tuners differed and is discussed. Tuners assembled with the selected cores have operated satisfactorily at R.F. levels above 100kVA per core.

Ferrite High-Loss Effect

The high-loss effect, a time-dependent form of magnetic breakdown, was observed early in the core testing program.^{1,2} Because it, rather than heating, dominates high-voltage operation of the cavities, we documented some of its features in testing 4,000 cores, 8"OD by 5"ID x 1" thick, of Ni-Zn ferrite. All four varieties of ferrite, Trans-Tech, Tohoku, Toshiba and Stackpole, exhibited the effect, but at widely-differing power levels.

Fig. 1 is typical of the result of the effect in a ferrite core operated at high power level (5kW) in the test cavity 9C. We could impedance-match the loaded test cavity accurately to the RF generator during any part of the pulse.

For routine production testing, we chose to impedance-match during the initial part of the envelope, and use the developing mismatch signal from a directional coupler as an indication of the onset of the high loss.

The following correlations were observed:

1. Dense ferrites are more susceptible than porous ferrites. We therefore favored porous ferrites in core selection. The weight of an individual core was taken as a measure of its porosity, because the core dimensions were known accurately.
2. The power threshold of the high-loss effect is not correlated with the low-level Q, but the low-level Q is in fact maintained during the initial portion of the pulse. Because we intend to operate the ferrite near but below the high-loss threshold we preferred high Q cores but only if the loss threshold was high as well.
3. All cores recover to the low-loss state in about 100 usec with no detectible permanent effect.
4. Strong D.C. magnetic biasing (50,000 amp-turns/meter) raises the threshold but does not eliminate the effect.

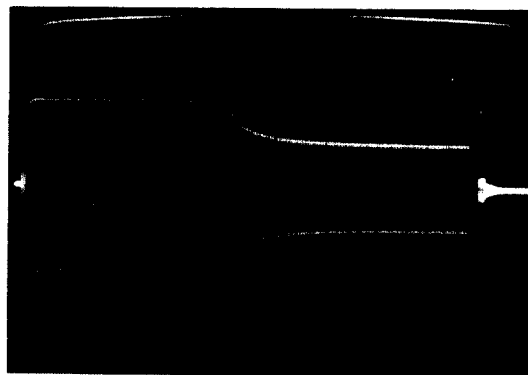


Figure 1 High Loss (0.2ms/DIV)

5. Hrf rather than Brf tends to govern the ferrites performance. In the design of tuners, therefore, we were more limited with respect to rf current than with respect to rf voltage per se.

Ferrite Testing

The low power test utilized a frequency synthesizer under the control of a small computer, powering the test cavity C.W. via a small terminated loop near a cavity current maximum. A vector voltmeter synchronized by the synthesizer monitored the cavity power level. To plot system Q, the computer stepped the frequency synthesizer through the cavity resonance with and without a ferrite core present. The empty cavity test was done once a week. A hydraulic system allowed quick disconnection of the 25,000 ampere bias bus bar that threads through the center of the coaxial test cavity and the shorting plate on the end of the cavity, facilitating insertion and withdrawal of the ferrite core under test. The output of the test was a strip plot of the response, the resonant frequency, the system Q, the D.C. Bias current on the axis of the coaxial cavity, the μ and Q of the ferrite core, the equivalent series R and L of the ferrite core, and the μQf product. This low power test was done at three values of D.C. Bias. The ferrite core was gaussed to 28,000 At/m and left in the remanent state preliminary to any testing.

The high power test was done right after the low power test by reconfiguring the proper leads and cables. A 1% duty cycle was used at high power. The D.C. bias was adjusted for a μ of 4.5 at a frequency of 36.67 MHz. The frequency synthesizer drove a cascaded chain of distributed amplifiers terminating in a 5kW power amplifier. The drive loop to the test cavity was mechanically adjustable to achieve an accurate match to the

50 ohm input cable. Matching was done by observing the signal from the downstream port of a high power directional coupler tuning for a minimum signal as the drive loop distance from the test cavity end was changed and minor frequency connections made. A calibrated pickup loop, securely mounted in the test cavity near one of the shorted ends, was used to enable calculation of the short circuit RF current at the cavity ends. The upstream port of the directional coupler permitted measurements of a known fraction of the input voltage (hence power) to the cavity. The loop voltage and the upstream port voltage were measured one at a time on a dual trace oscilloscope by adjusting the amplitude of a CW oscillator to visual equality to the pulsed output signal under investigation. Simultaneously, a vector voltmeter measured the CW oscillator amplitude. If the core experienced time dependent high loss the input power was adjusted so that two milliseconds of normal, non high loss operation existed before the high loss was observed. (See Fig. 1) Input to the computer for the high power test was an operator indication if high loss was observed, the loop voltage, the loop distance for a 50 ohm match, the upstream directional coupler voltage, and the D.C. current in the center bus bar. The high power test output from the computer was the short circuit RF current, the equivalent series R of the test cavity, the power delivered to the cavity plus core, the power to the cavity, the power to the core, the equivalent series R of the ferrite core, the ferrite Q, the μQf product, the drive loop distance from the end the test cavity, and the D.C. bias.

Core Selection Criteria

The Booster accelerator tuners used ferrite toroids of two manufacturers. These were arranged in the tuners to take advantage of their differing properties. The first nine cores, counting from the shorted ends of a tuner, were of Stackpole manufacture. The remaining five cores were those made by Toshiba. Thus there were 14 core positions and a total of 28 cores per tuner.

The Stackpole cores in position 1 through 9 from a shorted end of a tuner were assigned by the distance of the drive loop from the shorted end of the test cavity under a 50 ohm matched condition. The shorter this distance, the lower the position number of the core or the closer to the shorted ends of a tuner. This distance of the drive loop in the test cavity is inversely proportioned to the Q of the ferrite core. Thus the highest Q Stackpole cores were placed closest to the tuner's short circuited ends. For those position numbers in the tuner for which the distance of the drive loop in the test cavity was too coarse a determiner of position, the weight of the core (related to porosity) was used to fur-

ther determine the position number of a core. The lighter cores were always placed in positions nearer the shorted ends of the tuner when one value of distance of the drive loop in the test cavity had to be used for more than one position number in the tuner. In no case were Stackpole cores used for Booster accelerator tuners if they were heavier than 2,200 gm, or the loop voltage in the test cavity was less than 2.5 volts.

The Toshiba cores in tuner position numbers 9 through 14 were assigned by the loop voltage in the test cavity while the core was undergoing a specified amount of time dependent high power loss. The higher the loop voltage the lower the tuner position number or the closer the core to the shorted ends of the tuner. The loop voltage in the test cavity was used to calculate the short circuit RF current at the end of the test cavity.

No Toshiba core was used if its drive loop distance from the shorted end of the test cavity was greater than 2.63 inches.

The Main Accelerator tuners used only Stackpole ferrite cores. There were 10 tuner position numbers and 20 cores per tuner. No cores were used that experienced time dependent high power loss, or that weighed more than 2,125 grams, or that had test cavity loop voltages less than 3.0 volts. Only those cores whose test cavity drive loop distance were in the range from 2.61 to 2.74 inches and whose bias millivolts (corresponding to a given D.C. bias current) were in the range from 240.0 to 339.9 mv were used. The cores were assigned to position numbers in the tuners by weight, the lighter cores going to the lower position numbers nearer the short circuited ends of the tuners.

References

1. The first NAL report on the loss effect appears in the NAL Monthly Report of Activities, October 31, 1969; NAL-33-0090.01.
2. An apparently similar time - dependent loss effect, in the frequency range 2.8 - 8.1 MHz, was observed by G. Nassibian and D. Zanaschi at CERN - private communication from K.H. Reich, SI Division to Q.A. Kerns, NAL.
3. "Stackpole 8 Inch Production Cores"; Edition I; 8/21/70.
4. "Stackpole 8 Inch Production Cores"; Edition I; Supplement I; 11/5/70.
5. "Toshiba 8 Inch Production Cores"; Edition I; 11/3/70.
6. "Notes on 4000 Core Test Program", Q.A. Kerns; 3/5/70.

These last four references are unpublished NAL memos.