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ENERGY LOSSES ON TOKAMAK STARTUP*

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ABSTRACT

The energy loss in a torus vessel during startup is now an important factor in a power-producing tokamak design. The torus design cannot be based on a system which minimizes the conductivity with resistive structures as in present experimental devices. If the resistivity of the torus is too high, the reactors are subject to damage from an uncontrolled fast shutdown such as a disruption. The thermal and magnetic stored energy due to the plasma current loop is several hundred megajoules, which can produce melting of the torus wall. To prevent excessive damage, a low resistance passive circuit must be provided close to the plasma edge. Another desirable design feature is to make all vacuum seals as far away from the plasma as practical. Thus, the reactor torus designs need an inner low resistance shell and an outer high resistance shell. In addition, the superconducting dewar and coil support structures provide paths for toroidal currents to flow.

During the startup of a tokamak reactor using poloidal field (PF) coils to induce plasma currents, the conducting structures carry induced currents. The associated energy losses in the circuits must be provided by the startup coils and the PF system. This paper provides quantitative and comparitive values for the energies required as a function of the thickness or resistivity of the torus shells.

The tokamak torus design should have a good conducting shell near the plasma and a high resistive shell for the external torus and the cryostat enclosure. The good conductor near the plasma slows down the disruption current decay and provides self-stabilization for vertical and horizontal plasma position control. Its toroidal conductivity is limited by the need to have good penetration of the neutrons into the breeder blanket material. The inner shell conductivity is also affected by the divertor, vacuum piping, instrumentation penetration, fueling, auxiliary heating systems, and the shield requirements. The outer shells do not provide any electromagnetic advantages, and hence the resistance should be as high as practical. The calculations provided in this paper can be used to determine the size and cost of the systems as a function of the resistances of the structures. The results can thus be used to guide the preliminary concepts for the electromagnetic characteristics of a tokamak.

INTRODUCTION

A study was initiated to evaluate the resistivity of the various vacuum vessel structures with respect to the startup pulse. The aim of the study was to obtain numbers for the energy losses in the various structures as a function of their resistivity.

The previous electromagnetic studies on the Fusion Engineering Device (FED)[1] determined that good passive conductors near the plasma provided protection during disruption. This is accomplished by increasing the current decay phase of disruption and reducing the thermal energy which is dissipated on the first wall surface that contacts the plasma. These good conducting passive circuits near the plasma require high startup energy and low position control field energy. High conductivity toroidal circuits which are not well coupled to the plasma only increase the startup and position control losses.

Good passive conductors near the plasma versus a conducting liner are not considered as being essentially different if the passive conductors are a grid of conductors in both the radial and toroidal direction. For example, providing a structure support at the first wall by using high conductivity metal between each module of the breeder blanket and then interconnecting these supports from sector to sector could provide a good electromagnetic first wall

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design. A good inner grid or shell may reduce disruptions; however, even if the number of disruptions is not reduced, such an arrangement will reduce the thermal heat damage to the first wall, reduce the electromagnetic forces on the modules themselves, and prevent arc damage during a disruption.

The following information is believed to be useful in attempting to quantify the energy losses in any practical energy producing tokamak.

DESCRIPTION OF STUDY

For the calculations, the startup characteristics of the plasma were assumed to be as givn in Fig. 1.[2] The plasma is initiated on the outer edge of the chamber, and it starts as a 20-cm-radius plasma. It builds up to full 6-MA value centered in the chamber in approximately 10 s.

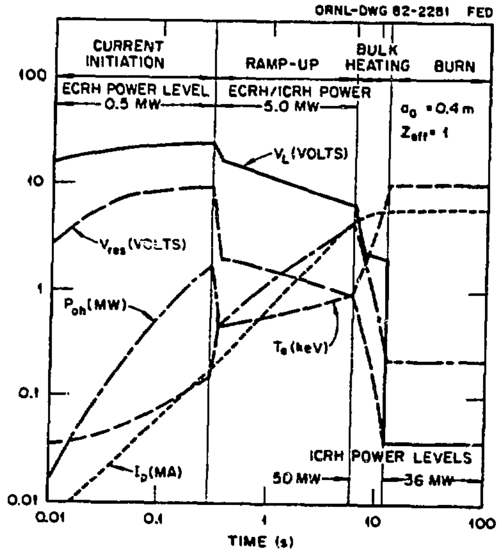

Fig. 1. Time evolution of key parameters during an expanding radius startup of a clean 0.4-cm minor radius plasma with rf assist

The bucking cylinder and toroidal field (TF) intersupport structures, as well as the superconducting dewar, were considered as having a resistivity such that they would have an electrical impedance equivalent to a 0.2-cm solid stainless steel structure (see Fig. 2). The plasma chamber itself was considered as two toroidal structures. The first, near the plasma outer scrape-off region was called the inner shell. The second at the outer boundary of the neutron shield was called the outer shell. The bulk shielding itself was considered to be sufficiently laminated in the toroidal direction as to have a negligible effect on the induced torus currents. The bulk shield was encased or fitted into the inner shell in such a manner as

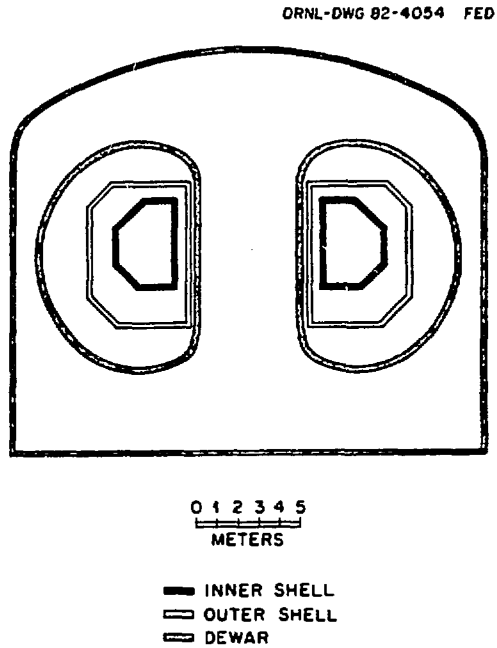

Fig. 2. Torus structures included in the study

to have no net effect in the equivalent torus resistance.

The variables in this study were the torus inner and outer shell resistivities, expressed as the thickness of the stainless steel.

The computer program was set up as multimesh equations, including the mutual impedances between conductors. The plasma impedance was varied as a function of the plasma current and plasma minor and major radii. The plasma was allowed to grow in radius and move toward the center of the vessel as its current increased. This change in size and position resulted in variable self- and mutual inductances.

The utilization in Fig. 1 for the plasma resistive voltage drop resulted in the assumption of rf-assisted startup as described on the figure.

The data were obtained by providing a set voltage on the startup coils and allowing this driving function to remain constant until a predetermined plasma current was obtained. This was equivalent to assuming that an initial current was applied to the startup coils and they were made to discharge at a constant rate.

The original study was aimed at the FED baseline design, but the configuration was made general rather than specific for FED. The various devices being studied by the Fusion Engineering Design Center (FEDC) were undergoing changes with respect to the torus structure when this study was originated.

Since no specific detailed configuration had been selected for the reactor-relevant tokamak, it was not the purpose of the study to try to optimize the startup coil location or current wave shape. Two locations were reviewed and various times for the length of the initiation pulse were made, but these were only to indicate the trends in obtaining optimization for specific designs.

RESULTS

The wall thickness on the dewar miscellaneous structure was held constant, and the inner and outer torus shells were varied. The inner shell was varied from 1 to 10 cm of equivalent solid stainless steel, and the outer shell was varied from 1 to 5 cm of equivalent stainless steel. The basic data were taken with a voltage of 30 Volts per turn impressed on the four startup coils, which were located at the corners of the torus. These were inside the TF bore and outside the torus vacuum enclosure (the outer shell).

The purpose of the study was to determine the startup requirements; hence, there was no effort to obtain the proper wave shape near 6 MA. The data tabulated in the analysis of the results was for the condition where 4.5 MA of plasma current is obtained, but in all cases it was determined that the FED baseline current of 6.0 MA could be obtained utilizing only the EF and OH coils. The OH and EF coils were operated in accordance with the wave shape, as specified in Fig. 3 (producing approximately 2 V per turn for a 20-s plasma current rise time). The energy loss data are presented in condensed form in Table 1 and Fig. 4. Typical output curves are shown in Figs. 5 and 6. The important observations are given below.

1. The losses in the outer shell and inner shell were independent of each other. For example, the loss for a 1-cm-thick outer shell was essentially 14 MJ for all cases of 1- to 10-cm-thick inner shell.

2. The losses in the outer shell were linear with respect to thickness, and they were the dominant losses for most cases considered.

3. The losses in the inner shell were 17 times less than those on the outer shell with equally thick shells up to an inner shell thickness of 5 cm. Above 5-cm thickness for the inner wall, there was a sharp increase in the inner wall losses.

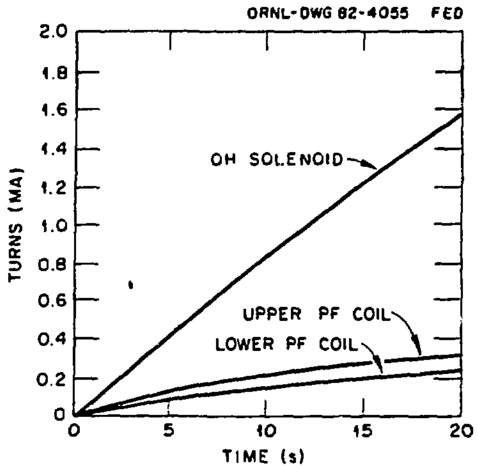

Fig. 3. PF current wave shapes

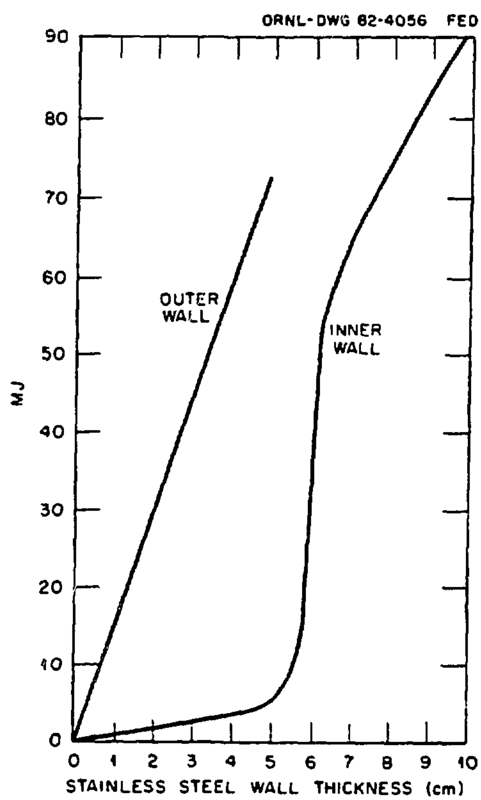

Fig. 4. Energy losses on startup vs wall thickness.

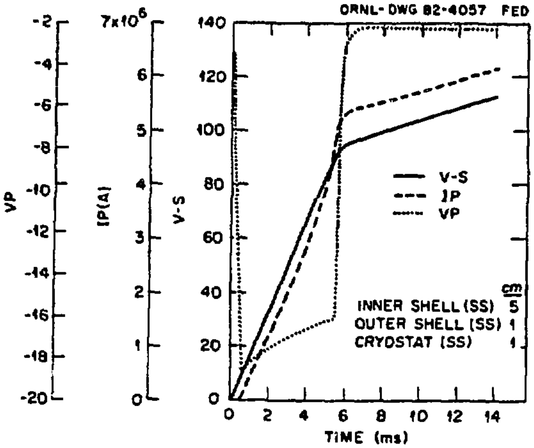

Fig. 5. Baseline pulse start data.

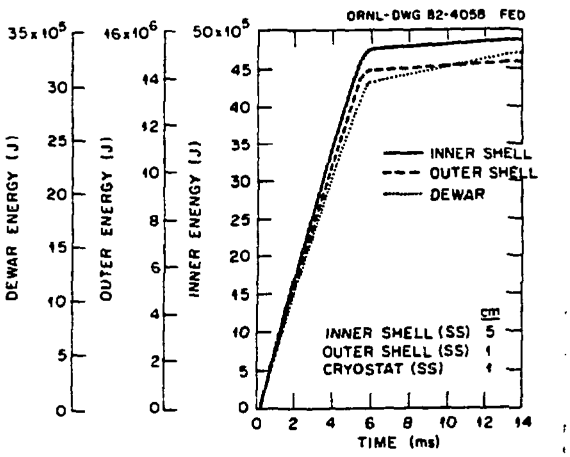

Fig. 6. Baseline pulse start data.

4. The reason for the step change in the inner wall losses was not investigated sufficiently to provide an understanding of the nonlinearity.

5. For the system studied, a good design for the shell resistances is a 5-cm equivalent inner shell resistance and an outer shell of about 0.25 cm or a ratio of 20 to 1 in resistance of the inner and outer shells. (The 5-cm inner shell will result in a disruption current decay of approximately 30 s and will not produce wall melt layers.)

6. The location of the startup coils was moved inward towards the plasma (inside of the outer shell). The calculations gave similar results except that the step charge in the inner wall losses did not occur until a resistance equivalent to approximately 8-cm thickness was obtained. It was concluded that the position of the startup coils should be reviewed in any final design, but there is not a great deal to be gained by moving the startup coils inside of the outer vacuum shell.

7. There were a few observation checks made in reducing the length of time in the startup pulse and increasing the rate of rise in the PF coils. (See Fig. 7 and 8 for short pulse output curves.) There was an indication that a short pulse could result in a factor of 2 reduction in wall losses. There was also the indication that a high voltage pulse for the first half second or so followed by a reduced pulse would be advantageous. Providing an initial coil current with a exponential decay of several seconds may be the most practical wave shape.

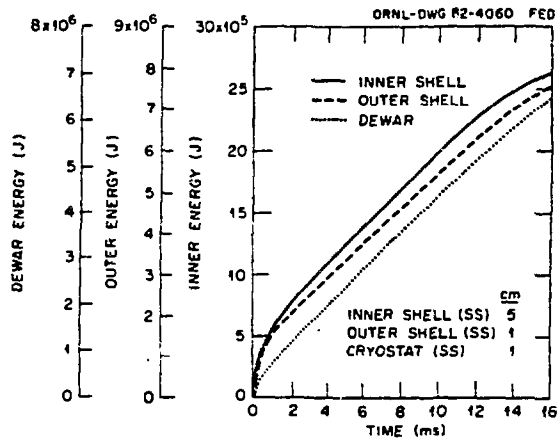

Fig. 7. Short-pulse start data.

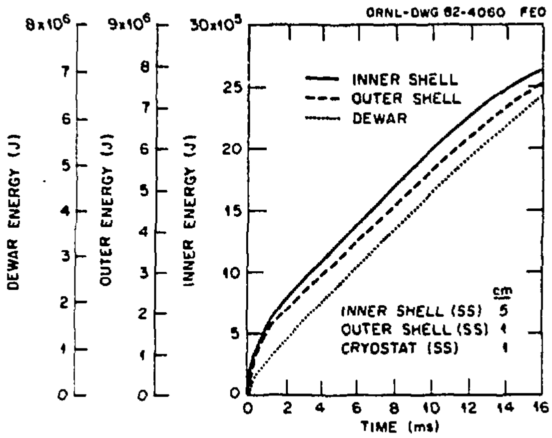

Fig. 8. Short-pulse start data.

REFERENCES

1. John G. Murray and George Bronner, "Disruption Model", Princeton Plasma Physics Laboratory 1909 (July 1982).

2. S. K. Borowski, Y-K. M. Peng, and T. Kammash, "RF Assist Current Startup in the Fusion Engineering Device (FED)," ORNL/TM-8319 (August 1982).