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DESIGN SURVEY AND CONCEPTUAL DEFINITION
OF A REACTIVITY OSCILLATOR
FOR THE FAST TEST REACTOR

October 1969

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ERRATA

Add figure number and caption on page 13 as follows:

FIGURE 4. *Fermi Oscillator Mechanism*

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DESIGN SURVEY AND CONCEPTUAL DEFINITION
OF A REACTIVITY OSCILLATOR FOR THE FAST TEST REACTOR

P. K. Telford

Engineering Department
FFTF Project

October 1969

BATTELLE MEMORIAL INSTITUTE
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DESIGN SURVEY AND CONCEPTUAL DEFINITION OF A
REACTIVITY OSCILLATOR FOR THE FAST TEST REACTOR

By

P. K. Telford

ABSTRACT

A survey was completed of reactivity oscillators that have been designed for various nuclear reactors. The experience accumulated by each design was reviewed. Previously successful, specific design features or choices were selected and recommended for initial design guidance to the designer of an oscillator for the Fast Test Reactor (FTR). A conceptual definition embodying the selected design choices was generated.

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DESIGN SURVEY AND CONCEPTUAL DEFINITION OF A REACTIVITY OSCILLATOR FOR THE FAST TEST REACTOR

P. K. Telford

INTRODUCTION

GENERAL OPERATING THEORY

An oscillator is a device which predictably varies the reactivity of a nuclear reactor. The input reactivity perturbation is correlated with the resulting flux perturbation to permit computation of the reactor transfer function as well as other nuclear parameters over a variety of operating conditions. The transfer function is used to determine the reactor stability and feedback characteristics. The input reactivity variation is accomplished by periodically exposing a neutron poison, a reflector, or source to the reactor core. Reactor oscillation theory and techniques are briefly discussed in References 1 and 2.

The desirability of a reactivity oscillator for the Fast Test Reactor (FTR) has been expressed in References 3 and 4. Tentative guidelines for conceptual definition were stated as a few cents peak-to-peak worth and a frequency range of 0.001 to 10 cycles/sec.

OSCILLATOR DESCRIPTION

The system necessary to measure the transfer function of a nuclear reactor using the oscillator technique consists of the following three parts:

- The oscillator rod is a combination of neutron poison, source, or reflective materials placed in the reactor core.* The material configuration is such that when the

* For purpose of discussion, the word "poison" will refer to those materials in the oscillator rod. The discussion will also be oriented toward fast reactor cores.

rod is either rotated or moved axially, a corresponding reactivity variation results. The poison section is attached to the drive through an extension shaft.

- The oscillator rod drive supplies the motivating force to the poison rod so that the rod is oscillated through a wide range of frequencies within narrow limits of variation. The drive system must provide a continuous, accurate signal of poison section cyclic frequency and position.
- The transfer function analyzer (TFA) consists of the electronic equipment necessary to correlate the oscillator rod motion with the resulting reactor flux oscillation in order to record, compute, or permit computation of the transfer function.

STUDY OBJECTIVES

The purpose of the study reported herein was to:

- Survey oscillator state-of-technology.
- Evaluate the possibilities and alternatives of specific oscillator design features as applied to FTR requirements.
- Summarize potential problem areas in oscillator design.
- Provide recommended design choices from previous user experience upon which to establish the prototype design of an oscillator for the FTR.

SUMMARY

Many different reactivity oscillator systems for measuring transfer functions of nuclear reactors have been designed and fabricated. A number of typical designs are summarized in Table 1 of this report. Reactivity oscillator systems designed for service in liquid metal-cooled nuclear reactors, and accorded special attention in this survey because of possible application to the FTR design, were Fermi, EBR-II (two separate designs), SRE, SEFOR, Dounreay, and Rapsodie.

The following assessments and conclusions are based on a review of the experience of other oscillator designers and users.

- Oscillator rod designs for zero power reactors have been generally successful except for minimal bearing problems. The achievement of a completely successful oscillator rod design for sodium-cooled fast reactors has been difficult. Most of the difficulties are related to bearings, operation in the sodium environment, and to rod distortion or bowing due to thermal or dynamic effects.⁽⁵⁾ The bearing problem is inherent with the molten sodium or sodium vapor environment. However, it appears that, through the application of past experience and current technology, an oscillator rod (and extension shaft) bearing design can be achieved with a minimum of foreseeable problems and a high level of confidence in the success of the initial design. The thermal and dynamic design of the oscillator rod and extension shaft is the most critical aspect of the entire system. Thermal bowing, rubbing, and misalignment are all factors affecting the accuracy of the experiment, the life of the rod and extension shaft bearing and, consequently, the success of the drive design. Rotary oscillators present inherent problems of dynamically induced bowing, whip, and stability at critical speeds. The Fermi design appears to have been more successful than most in this respect. It follows that the oscillator rod, guide tube, and extension shaft will require extensive development and testing in a prototypical non-neutronic FTR environment in order to assure successful performance in the FTR.
- Only minor difficulties have been reported with the operation of the various drive systems designed for oscillators. Although hydraulic drive systems have been successfully employed, most designers have used an electric motor as a motive force. The motor is used to drive various speed reduction devices in order to oscillate the rod. Some of

the minimal difficulties reported have included gear slippage on shafts, shaft misalignment, clutch problems (where employed), and maintaining constant speeds. An extensive developmental testing program will be necessary to verify satisfactory drive performance when the motor is coupled to the oscillator rod under simulated service conditions. The oscillator drive and rod must be developed as one assembly because of their intimate relationship, and because drive deficiencies are usually not evident unless the drive and rod are coupled.

- The Transfer Function Analysis equipment to be furnished as a part of the oscillator assembly will most likely consist of only those devices necessary to provide a taped recording of all parameters desired during an experiment. Thus, the true analysis of the experimental data will not be provided by the oscillator assembly but by the operator subsequent to the tests. The subsequent analysis of recorded information is more desirable from an experimenter's viewpoint.⁽⁶⁾ The oscillator input to the recorder need only be a suitable electric signal of oscillator rod speed and position. All other input signals and subsequent data analysis must be provided by equipment designed to interface directly with the oscillator system.

RECOMMENDATIONS

The recommended choices of the basic features for conceptually defining the FTR oscillator are as listed in the following and discussed in the body of this document. The selected features are believed to constitute the best choices from the standpoint of FTR requirements, amount of prior usage, favorable experience, and advances in technology. The views in Figures 10 and 11 present composite conceptual definition of the mechanical aspects of the oscillator. The recommended design choices, intended as initial guidance to the designer of the FTR prototype oscillator, are as follows:

- Oscillator rod movement - rotary
- Drive type - electric motor
- Speed control - variable speed electric motor
- Speed reduction - variable speed drive
- Drive attachment to rod - forks
- Rod configuration - Fermi high power rod concept (offset pins)
- Seals - standard assemblies for Na service (rotary shafts)
bellows (reciprocating shafts)
- Bearings - journal bearings in Na - Colmonoy, Stellite
journal bearings in Na vapor - Aluminum Bronze, Colomony
conical thrust bearings in Na - Kentanium
- Transfer Function Analysis - to be performed on taped recording of data.

DISCUSSION

REACTIVITY OSCILLATOR SURVEY

Table 1, entitled "Reactivity Oscillator Survey," tabulates a number of oscillators designed for various reactors. The table includes all oscillator designs from liquid metal-cooled reactors of special interest to the FTR oscillator. The table also includes a cross-section of oscillator designs from other reactors. These designs are included to:

- Provide the reader with an awareness of other "oscillator" concepts.
- Provide (if needed) a survey of zero power reactor oscillators for possible application to the Nuclear Proof Test Facility.
- Provide additional insight into other oscillator drive mechanism designs of possible interest to the FTR.

The following general observations are made from a review of the information in Table 1:

- Both hydraulic and electric powered drives are commonly used. The Rapsodie is unique in that it is the only liquid metal-cooled reactor using a hydraulically driven oscillator. The axial movement of this oscillator is also somewhat unique with the exception of the abandoned EBR-II Mark I design (Figure 1) and the SEFOR design (Figure 2).
- Either rotary or axial oscillator rod motion is used. Axial motion is often chosen for the lower frequencies, or where variable worth is desired. However, variable worth rotary oscillators using a shielding "window" technique have been built.
- There appears to be no commonly accepted method of varying or controlling the speed of oscillation, and no particular combination of electric motor type and speed control method has emerged.
- Previous experience indicates that the most likely FTR oscillator problem areas will be related to the high temperature sodium environment. These problem areas are: bearings, sodium sealing techniques, oscillator rod thermal bowing, and extension shaft stability.
- In power reactors, the proper design of the oscillator rod is basic to the success of the oscillator system. Coolant flow distribution through the poison and structural sections of the rod is crucial in controlling the bowing and rubbing caused by thermal distortions. These distortions are also aggravated by the dynamic forces introduced into the system.
- Oscillator shaft dynamic sealing techniques have taken the form of bellows, labyrinths, packing or O-rings with inert gas purge. Some techniques have employed no seals. In the latter cases, the oscillator motion is magnetically transmitted through the walls of a sealed thimble.

FIGURE 1. EBR-II Mark I Reactivity Generator Assembly

FIGURE 2. SEFOR Oscillator Drive Mechanism

- The placement of the oscillator within the core lattice is dictated by user requirements and space availability. Some have been designed to be placed in any control (or safety) rod position. It is recognized, of course, that larger total worths are required nearer the center of the core for rotary oscillators in order to produce reactivity perturbations equivalent to those where a steeper worth gradient exists. In power reactors, this location results in compounded heat generation rates because of both the higher oscillator worth required near the core center (because of the flatter worth profile) and the greater flux nearer the core center. Consequently, power reactor oscillators in or near the core reflector are favored unless only the zero power transfer function is measured.
- Sodium service bearing technology is continually being advanced. Journal bearings in rotating oscillator rods and shafts have found general acceptance. However, material combination choices have varied, and successful combinations in one application have not necessarily proved successful in other applications.

DESIGN CHOICE RECOMMENDATIONS

Based on the philosophy of applying state-of-technology when possible to the FTR developmental efforts, existing proven concepts or features of various oscillator components used in other reactors should be utilized for the FTR oscillator design. Design choices of previously successful concepts or features are herein selected and recommended to form a composite oscillator concept.

The design choices recommended in this document incorporate features from each of the oscillator designs found to have accumulated successful operating experience. Where no particular advantages or disadvantages are evident, general acceptance by prior users is considered the best design choice. In this

respect, a more successful design can usually be produced by using tested concepts with known but correctable deficiencies, rather than by placing trust in the success of a design embodying untried principles.

Based on the limited functional specifications,⁽³⁾ the various aspects of FTR oscillator design choices are discussed and justified in the following paragraphs. Supporting references are listed in Table 1.

Oscillator Rod Movement (Rotary or Axial)

Design Choice - Rotary

Oscillators moving axially are inherently adaptable to variable amplitudes. However, this type of motion is more difficult to seal, requires higher forces, is frequency limited (a function of amplitude), and has either limited or unfavorable sodium experience. The EBR-II Mark I oscillator (Figure 1) moved axially but was discarded and replaced by a rotary model after a ball bearing failure in 1964. The bearing failure, however, was not necessarily attributed to the design of the device. An axial motion oscillator (Figure 3) used by Rapsodie performed favorably during pre-startup tests in 1966. No other more recent Rapsodie oscillator experience has been obtained. The SEFOR oscillator (Figure 2) also moves axially, but its maximum frequency is 0.5 cps and no actual in-reactor experience has been obtained to date.

Rotary oscillators appear less difficult to seal against sodium or sodium vapor, can easily be made to rotate at 10 or more cycles/sec, and have accumulated extensive experience in sodium in the Dounreay, Fermi (Figures 4, 5), and EBR-II (Figures 6, 7) reactors. The disadvantages include fixed amplitude (usually), more difficult bearing problems, and shaft whip at higher speeds. These problems must be solved for each oscillator through a thorough design and testing program.

CROSS SECTION OF HIGH-POWER OSCILLATOR ROD

CROSS SECTION OF LOW-POWER OSCILLATOR ROD

FIGURE 5. Fermi Oscillator Rod Cross Sections

FIGURE 6. EBR-II Mark II Oscillator Rod Drive Assembly

FIGURE 7. EBR-II Mark II Oscillator Rod

Speed Control (Mechanical or Electrical)

Design Choice - Variable Speed Electric Motor

Constant oscillator rotary speed is paramount to reliable test results. Alternating current motors are used to obtain constant speed, and speed changes are accomplished by variable speed transmissions or disconnectable gear trains of many types. Although dc motor speeds can be easily varied, very low constant speeds are difficult to attain because, among other reasons, of the supply voltage ripple (usually rectified ac). However, one supplier claims that no load to full load speed control to 0.1% of maximum speed can be achieved using a tachometer-generator output as feedback to a dc motor controller. Direct current motor speed ranges as high as 200:1 are available with good control. Alternating current motors can also provide quite wide speed ranges with good control.

A properly designed variable speed motor could serve the three functions of driving force, speed control, and partial speed reduction for the four-decade speed range required. This combination of functions is important because of the space limitations imposed upon the oscillator drive by the FTR design. Thus, a variable speed electric motor is specified as the design choice.

Speed Reduction (Variable or Fixed)

Design Choice - Variable Speed Drive

The principal speed reduction methods used heretofore on electric motor driven oscillators have been of the following three types or combinations:

- Gear reducers coupled in parallel through disconnectable links (see SRE, Figures 8, 9).
- Transmissions in series.
- Variable speed drives.

Rotary motion is recommended for the FTR oscillator for the following considerations:

- There are inherent difficulties in obtaining the higher (to 10 cps) frequencies with axially moving oscillators. It is also usually desirable to increase the reactivity perturbation amplitudes of oscillation with frequency.⁽⁶⁾
- EBR-II discarded the axial concept for the rotary motion.^(7,8)
- There is general acceptance and much experience with rotary oscillators (see Table 1).
- A rotary oscillator requires less drive power than an axial oscillator of the same weight, inasmuch as the entire mass of an axial oscillator must be accelerated and decelerated twice each cycle.

Drive Type (Hydraulic, Pneumatic or Electric)

Design Choice - Electric Motor

For safety purposes, sodium environments preclude the use of hydraulic drive systems where other types are usable. Also, since high forces are not required for a rotary oscillator, hydraulic power is not needed. Although pneumatic systems could be used, their inherent sponginess results in speed control difficulties, especially with regard to possible intermittent rubbing of the oscillator rod. One advantage of fluid drive systems is the ease in selecting infinitely variable speeds. Rapsodie is the only liquid metal-cooled reactor using a hydraulically driven oscillator.

There are no outstanding deficiencies in the use of electric motor drives for oscillators, and much experience has been accumulated on them from a number of reactors. Again, experience and general acceptance take precedence, and an electric motor drive is specified as the design choice.

FIGURE 8. SRE Oscillator Drive Mechanism

Boral Poison Squares Mounted
on Rotor and Stator
of Rotary Sinusoidal Reactivity Device

Rotor and Stator
of Rotary Sinusoidal
Reactivity Device

FIGURE 9. SRE Oscillator Rod

The design of the speed reduction technique should be in accordance with the latest technology with respect to backlash, minimum numbers of components, space requirements, and maximum speed range. The optimum combination to meet these criteria would be 100:1 variable speed range drive motor coupled to a 100:1 variable speed transmission to satisfy the desired 10^4 speed range. The Fermi and EBR-II oscillators are driven through Graham transmissions. Other transmissions are also available with wide speed ranges and good control. Therefore, a variable speed drive is recommended for the FTR oscillator.

Drive Attachment to Oscillator Rod

Design Choice - Forks (primary) Gripper (alternate)

The method of drive attachment to the rod is largely dependent on whether the drive must be removed to facilitate core loading. Oscillator rods have been disconnectable through the use of a magnetic coupling (Dounreay), grippers (EBR-II), or with fork and collar (Fermi). Magnetic couplings are subject to slip since they are not directly mechanically coupled. EBR-II has had difficulties with bellows associated with the gripper and gripper indicator shafts. No difficulties with the fork and collar configuration used on the Fermi oscillator have been reported. Therefore, this type is designated as the primary design choice. The gripper type is considered as the alternate choice.

Rod Configuration

Design Choice - Fermi High Power Rod Concept (Offset Poison Pins)

A rotary rod should have both low mass and low moment of inertia to simplify balancing problems at all temperatures. Also, a minimum quantity of heat generating material should be used to minimize temperature gradients and associated thermal

bowing. A poison rod located near the core-reflector interface most nearly satisfies these requirements (as previously discussed herein).

The design of the rod itself is the most important aspect of oscillator design. Most previous difficulties have arisen because of temperature-inertial associated changes in rod profile resulting in bearing and rod bowing problems. The Fermi high power rod design concept (Figure 5) is recommended for the FTR since the design was evidently successful.

Seals

Design Choice - Standard Assemblies (Rotating Shafts)

Bellows (Reciprocating Shafts)

Bellows type shaft seals have commonly been used on reciprocating shafts in U.S. sodium cooled reactors. Fermi had no difficulties with the bellows on its oscillator. However, EBR-II has had gripper shaft bellows failures. E. Hutter of ANL believes that bellows life is reduced by vibrations resulting from the rotation of the oscillator. This problem is currently under study in an attempt to eliminate the bellows entirely on the oscillator grippers. Unless a gripper is used on the FTR oscillator, there may be no reciprocating shafts to seal. Therefore, for such standard applications as providing small allowances for thermal expansion, etc., bellows are recommended design choice.

Rotating shaft sealing techniques for sodium service are fairly well developed. Assemblies presently available for this service are expected to be readily adaptable to the oscillator.

Bearings

Design Choice - Journal Bearings in Na - Colmonoy - Stellite
Journal Bearings in Na Vapor - Alum/Bronze -
Colmonoy
Conical Thrust Bearings in Na - Kentanium

The proper choice of bearings for sodium service is recognized as a rapidly advancing technology. The detailed design of these bearings must be undertaken only after thoroughly studying previous designs and experience, since proper running clearances are imperative for successful service. Previous experience dictates the use of journal bearings on rotating oscillator shafts. Prior experience and usage at EBR-II and Fermi, as well as other reactors, dictates the material design choices as specified. However, the results of bearing investigations presently undertaken as a part of LMFBR studies⁽⁹⁾ may reveal improved materials which may be incorporated into FTR oscillator prototype design.^(7,9-13)

Transfer Function Analysis

Design Choice - To be Performed on Taped Recording of Data
Independent of Oscillator Development.

Various methods^(12,14) of transfer function analysis have been used and evaluated. The "synchronous" method was chosen in APDA studies⁽¹⁴⁾ as the best of four methods used on the Fermi reactor. This method measures the transfer function with good precision over the frequency range of 0.005 to 5.0 cps. A recent Westinghouse study⁽⁴⁾ also supports this conclusion. These methods employ an analog computer circuit to analyze the experimental data and compute the transfer function on-line.

It is also possible to record the experimental data and then perform a more thorough analysis at a more convenient time. A taped recording is also desirable from a number of other considerations.⁽⁶⁾

CONCEPTUAL DEFINITION OF AN FTR OSCILLATOR

Figures 10 and 11 provide an example of an oscillator design embodying the previously selected design choice recommendations. This design, essentially a combination of the EBR-II Mark II and the Fermi designs, differs significantly only in incorporation of the provisions for variable worth. Variable worth, it should be noted, is highly desirable from a physics standpoint. No other rotary oscillator has been designed with this provision for a liquid metal-cooled fast reactor other than by complete replacement of the poison section or pins.* Figure 11 illustrates a method of adjusting oscillator worth by varying the distance of the poison and balance pins from the axis of rotation. The adjusting ramp was selected in an attempt to eliminate the use of gears and screws in a high flux, molten sodium environment. The ramp adjustment shaft is positioned by a stepping motor located on the drive.

Another possible method of varying the oscillator worth is by varying its vertical position within the reactor core. This method was not illustrated in this report because of problems of unknown magnitude associated with positioning of the conical thrust bearing located on the lower portion of the poison section. This bearing, because it supports the rotating rod, would require raising or lowering to adjust the worth of the oscillator. Raising the bearing (by some undetermined method) into a region of higher neutron flux would only serve to impair its serviceability. This problem could possibly be circumvented by supporting the oscillator from above.

Similarly, the life of the poison section could be extended significantly through the limitation of burnup by

* *It has been reported that the Dounreay mechanism is vertically adjustable in the reactor core.*

FIGURE 10. FTR Oscillator Rod Control

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Sheet 2 of 2

tor Drive Conceptual Description

removing the oscillator from the core when not in use. This removal could be accomplished by simultaneously lifting the ramp adjustment shaft and the drive shaft. It should be noted that lifting only the drive shaft serves to actuate the disconnect devices on each end of the intermediate drive shaft. The poison section could then be so suspended as to withdraw it to a region of lower neutron flux. The male portion of the conical thrust bearing remains in the bottom of the oscillator guide duct.

For complete oscillator removal, the duct with the poison section inside is removed in the same manner as that for handling a FTR control rod.

The allowable drive mechanism space envelope is not necessarily that shown in Figure 10. Envelope requirements will be dependent on the location(s) selected for the oscillator, and on space requirements as dictated by preliminary design of the FTR.

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