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Director, Nuclear Reactor Regulation
Att Mr Dennis L Ziemann, Chief
Operating Reactors Branch No 2
US Nuclear Regulatory Commission
Washington, DC 20555

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PALISADES PLANT - TECHNICAL SPECIFICATIONS
CHANGE - IN-CORE DETECTORS ADDITIONAL INFORMATION

This letter is in response to questions received by telephone from the NRC on our In-Core Detectors Technical Specifications Change.

The Consumers Power Company version of the INCA program is being revised to accommodate five (5) levels of detectors. This will be performed by Consumers Power Company personnel.

The method used in synthesizing axial power distributions is outlined in the attached paper: "AXIAL POWER DISTRIBUTIONS FROM FOURIER FITTING OF FIXED IN-CORE DETECTOR POWERS" by Terney, Marks, Williamson and Ober, Combustion Engineering, Inc, 1975. The report gives the equations involved in the fitting procedure and quotes expected errors. The extrapolation distance δ is computed in the Consumers Power Company INCA code by running the XTG program and finding the value of δ that gives the best agreement between a fit based on calculated detector powers and the corresponding 12-node XTG shape for each assembly.

Attached are three figures showing examples of comparisons between computed assembly axial power distributions and the corresponding synthesized distributions based on five computed detector powers. The graph labeled 14 shows a current typical Palisades power shape with no control rods in the core, while the graphs labeled 20 and 26 are for a case with the group 4 rods inserted halfway. As shown by 14 and 20, the fitting method works extremely well for balanced and skewed power shapes. Figure 26 shows that while the fit is not as accurate for an assembly immediately adjacent to a control rod, both the magnitude and position of the power peak are still well represented.

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AXIAL POWER DISTRIBUTIONS FROM FOURIER FITTING OF FIXED IN-CORE DETECTOR POWERS

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ABSTRACT

A reliable method is needed for synthesizing flux detector readings into spatially dependent axial power shapes with a limited number of fixed in-core neutron detectors in an axial string. In this paper, the Fourier expansion technique for obtaining axial power distributions is examined. A wide variety of representative axial shapes are studied with four, five and six detector systems. The results show all the systems perform well. The use of five detectors instead of four increases the accuracy, while the use of six detectors gives little further improvement over the five-detector system. With five detectors and five Fourier modes, the standard deviation in the error in predicting the axial peak to average power ratio is about 0.8%.

AXIAL POWER DISTRIBUTIONS FROM FOURIER FITTING OF FIXED IN-CORE DETECTOR POWERS

INTRODUCTION

General

With a limited number of fixed in-core neutron detectors, a reliable method is needed to synthesize the detector readings into spatially dependent power distributions. Combustion Engineering's in-core detector analysis system (INCA) is such a method.(1–4) An integral part of the method is the procedure used to synthesize axial power distributions from the readings of a few detectors in an axial string. In this system, a method based on expanding the axial power distribution in terms of a few axially dependent Fourier modes is used.(1–6)

Formulation

The basic procedure is to assume that the axial power distribution in an assembly may be represented as the sum of the first N Fourier modes:

$$P(z)=\sum_{n=1}^{N} a_n \sin n \pi Bz \qquad (1)$$

where

P is the power per unit length,

z is the axial elevation in percent of the core height (H),

a_n are the unknown combining coefficients, and

$$B=\frac{H}{H+2\delta} \qquad (2)$$

Note that δ is the extrapolation distance, which usually is determined empirically.

The N combining coefficients are obtained by matching the power read by each of the N detectors to the integral of Eq (1) over the axial extent of each of the N detectors

$$d_i=\int_{z_i^{bottom}}^{z_i^{top}} dz \left(\sum_{n=1}^{N} a_n \sin n \pi Bz\right) \qquad (3)$$

$$i=1, \ldots N$$

where d_i is the power read by the i^{th} detector and z_i^{top} and z_i^{bottom} are the axial elevations of the top and bottom of the i^{th} detectors, respectively.

This can be done for all the detectors in a string, or for subsets. For instance, with four detectors, four modes could be used to match all four detectors simultaneously. Alternatively, the top three detectors could be matched with three modes, and the bottom three detectors with three modes. The actual power distribution would then be made of top and bottom segments from the two fits.

In this study, both the overlapping and continuous schemes were investigated. Also, various arrangements of four, five and six detector strings were examined to determine the best arrangement of each. The study was carried out by testing the various systems on a large number of typical PWR axial power shapes generated from one- and three-dimensional diffusion theory calculations at different times in life for different conditions.

RESULTS

Initial studies were done on a sample of 17 skewed power shapes from a set of 170 typical and highly skewed beginning-of-life (BOL), middle-of-life (MOL), and end-of-life (EOL) first cycle one-dimensional shapes. Typical examples of the shapes are given in Fig. 1. The use of four and five equally spaced detectors with lengths equal to 12% of the core height was investigated, as well as using subsets of three detector readings for the fitting. The pseudo detector readings were obtained by integrating the given shapes over the detector lengths. Then the fitting was done and compared to the given shapes. The boundary conditions (δ or B) were chosen to yield a mean error of near zero in fitting axial peak-to-average power ratios.

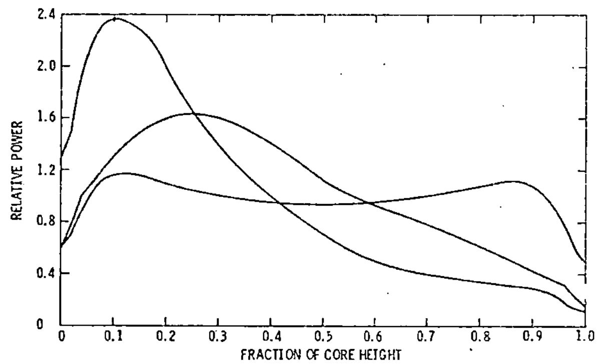

Fig. 1: Representative shapes from one-dimensional analyses

Table I gives the results for these 17 one-dimensional axial shapes with the best four and five detector arrangements. With four detectors, locating the centers of the segments at 20, 40, 60, and 80% of the core height led to the minimum uncertainty in the fitted axial peak. In the five detector system, the centers were located at 10, 30, 50, 70, and 90% of the core height. Two points are immediately apparent: One is that using the maximum possible number of modes is better than using groups of subsets. For four detectors, using four modes is slightly better than using two sets of three modes, similarly for five detectors and five modes.

TABLE I.

ERROR ANALYSIS OF THE AXIAL PEAK TO AVERAGE POWER RATIO FOR 1-D AXIAL SHAPES

Case	Mean Error	Standard Deviation	Maximum Error
4 detectors centered at 20, 40, 60, 80% of core height			
2 sets of 3 modes	0.1%	3.5%	9.3%
1 set of 4 modes	0.5%	3.1%	8.4%
5 detectors centered at 10, 30, 50, 70, 90% of core height			
2 sets of 3 modes	0 %	1.2%	2.7%
1 set of 5 modes	0.2%	0.7%	1.5%

$$\% \text{ error} = \frac{\text{real-fit}}{\text{real}} \times 100$$

Further, it is clear that a five detector system is an improvement over the four detector system. The reason for this is twofold:

(1) With five detectors, the peaks near the end of the core are seen better; whereas with four detectors these are hardly seen.

(2) With five detectors, five modes can be used, which gives a better chance of having a component with a peak in the right location.

This is illustrated in Figs. 2 and 3. Figure 2 shows the worst curve that occurred during a transient with four detectors, and Fig. 3, the same worst curve with five detectors.

In view of this success, a representative sample of 25 axial power shapes from three-dimensional calculations were analyzed with four, five, and six equally spaced detectors. This subset of regular, skewed, highly-peaked, rodded and unrodded distributions was taken from a group of 646 shapes generated during first and later cycle three-dimensional calculations. Some of the typical shapes are shown in Fig. 1. Each detector had a length of 10% of the core height. The locations were the same as before with the six detectors being centered at 10, 26, 42, 58, 74, and 90% of the core height. Again, the boundary conditions were selected to give a mean error in the axial peak-to-average power ratio of about zero.

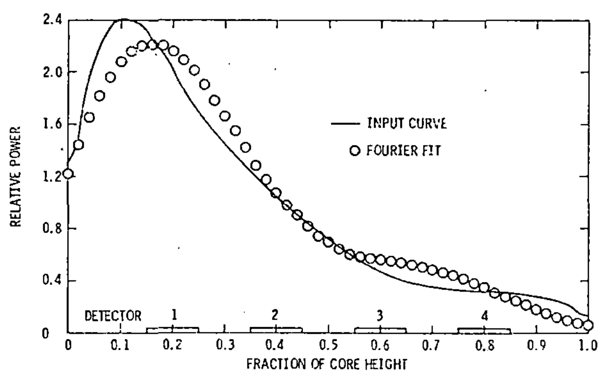

Fig. 2: Transient shape, four detectors

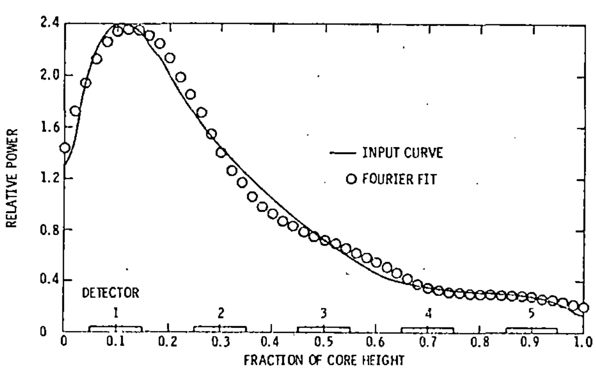

Fig. 3: Transient shape, five detectors

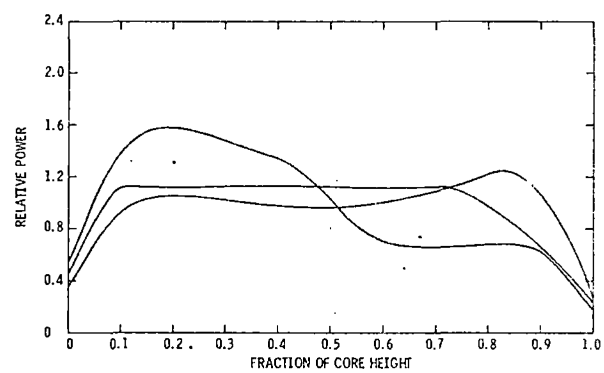

Fig. 4: Typical shapes from three-dimensional analyses

The results of the analysis are shown in Table II. Again the improvement in going from four to five detectors is apparent, as well as the limited extra gain in going to six detectors. The largest error occurs in a box which has very low power, since it is almost fully rodded, but which has distorted power distributions in the bottom 10% of the core below the rod. This is illustrated in Fig. 5 for the various cases. Such a box would not be a limiting case.

These results indicate that a five detector system is better than a four detector system, and that a six detector system does not give significant further gains.

These results are borne out when the entire set of 846 one- and three-dimensional shapes were considered. With five detectors, a single value of B was used to obtain the results given in Table III. For the four detector system, the best values of B were used for

TABLE II

ERROR ANALYSIS† OF THE AXIAL PEAK TO AVERAGE POWER RATIO FOR 3-D AXIAL SHAPES

Case	Mean Error, %	Standard Deviation, %	Maximum Error, %
4 detectors	−0.2	2.9	+12.5
5 detectors	−0.1	1.4	−6.0
6 detectors	−0.1	1.2	−3.7

† $\% \text{ error} = \dfrac{\text{real-fit}}{\text{real}} \times 100$

TABLE III

ERROR† ANALYSIS OF THE AXIAL PEAK TO AVERAGE POWER RATES FOR ALL SHAPES

Case	Mean Error, %	Standard Deviation, %	Maximum Error, %
4 detectors	0.1	1.4	+12
5 detectors	+0.1	0.8	−6

† $\% \text{ error} = \dfrac{\text{real-fit} \times 100}{\text{real}}$

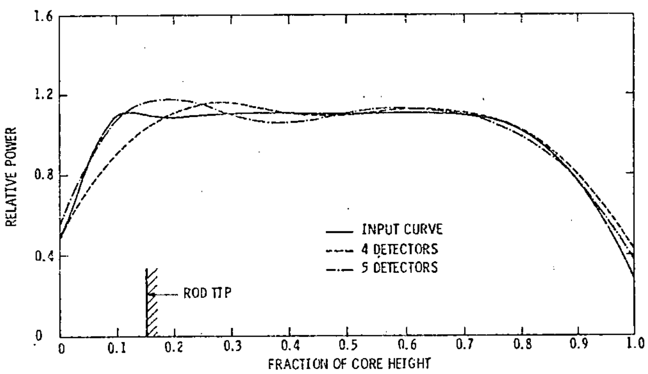

Fig. 5: Comparison of four and five detector synthesis for a bottom peaked distribution

each set of curves, *i.e.*, a different value for each time in life. With five detectors, there is little variation of the boundary condition with life. The expected standard deviation in the error in fitting the axial peak to average power is about 0.8%.

These results were all obtained with the smooth power distributions typical of C-E reactors, which have no sizeable local depressions due to Inconel grids, etc. If such grid effects are present, the results would deteriorate somewhat. Standard deviations of the error in the peak-to-average power ratio could increase by some 0.5 to 1%.

CONCLUSIONS

The concept of synthesizing axial power distributions from a limited number of detector readings with Fourier expansion modes is a viable concept.* A five detector system leads to expected standard deviations in the accuracy of the peak to average power ratio of about 0.8%. In addition, a unique fitting parameter in the form of an extrapolation distance can be determined which is valid for all times in life. The five detector system, thus, represents an advance over the four detector system, while a six detector system does not bring further significant gains.

* Other methods (*e.g.*, spline) for fitting the data were tried. None were consistently better than the Fourier approach.

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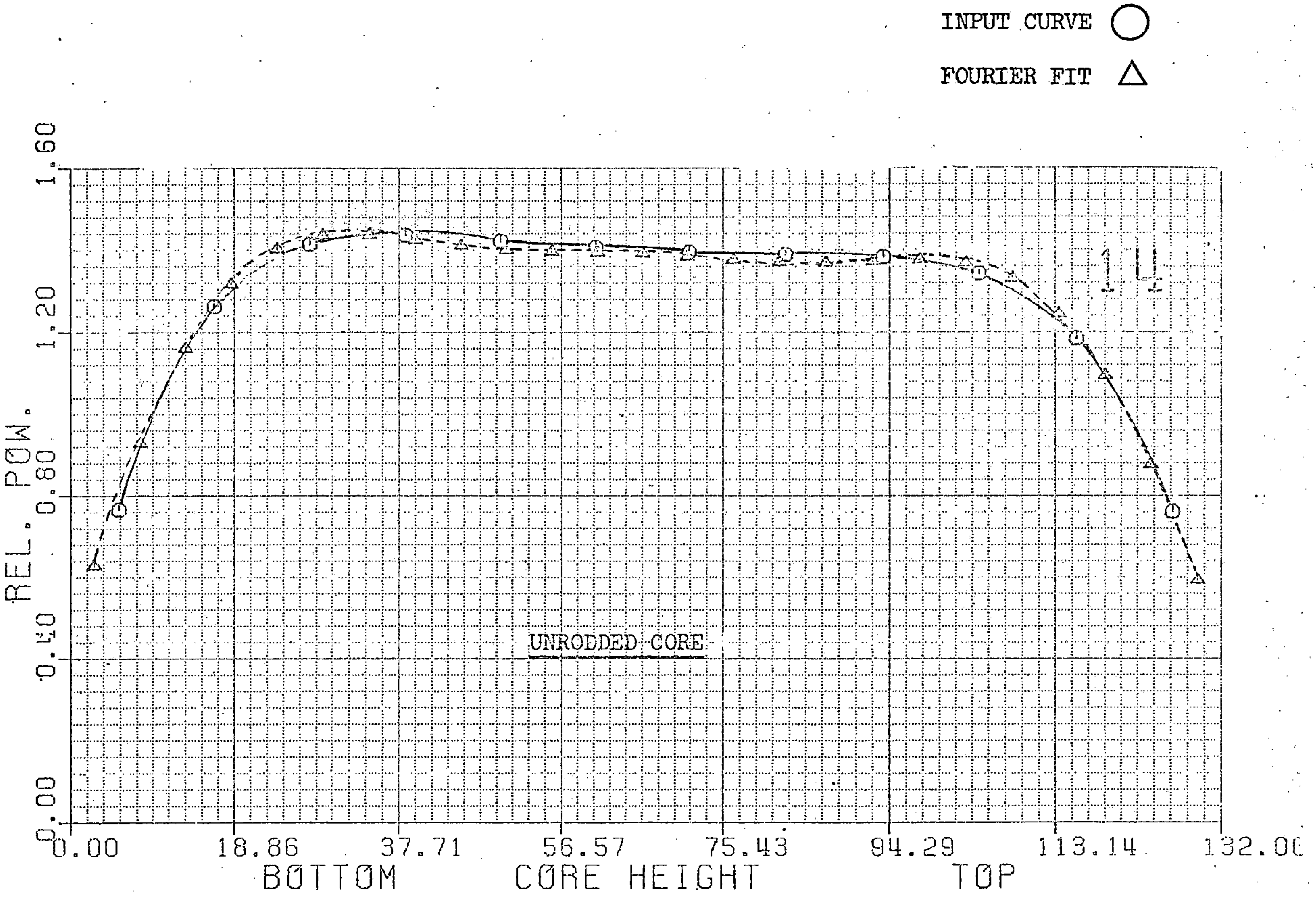

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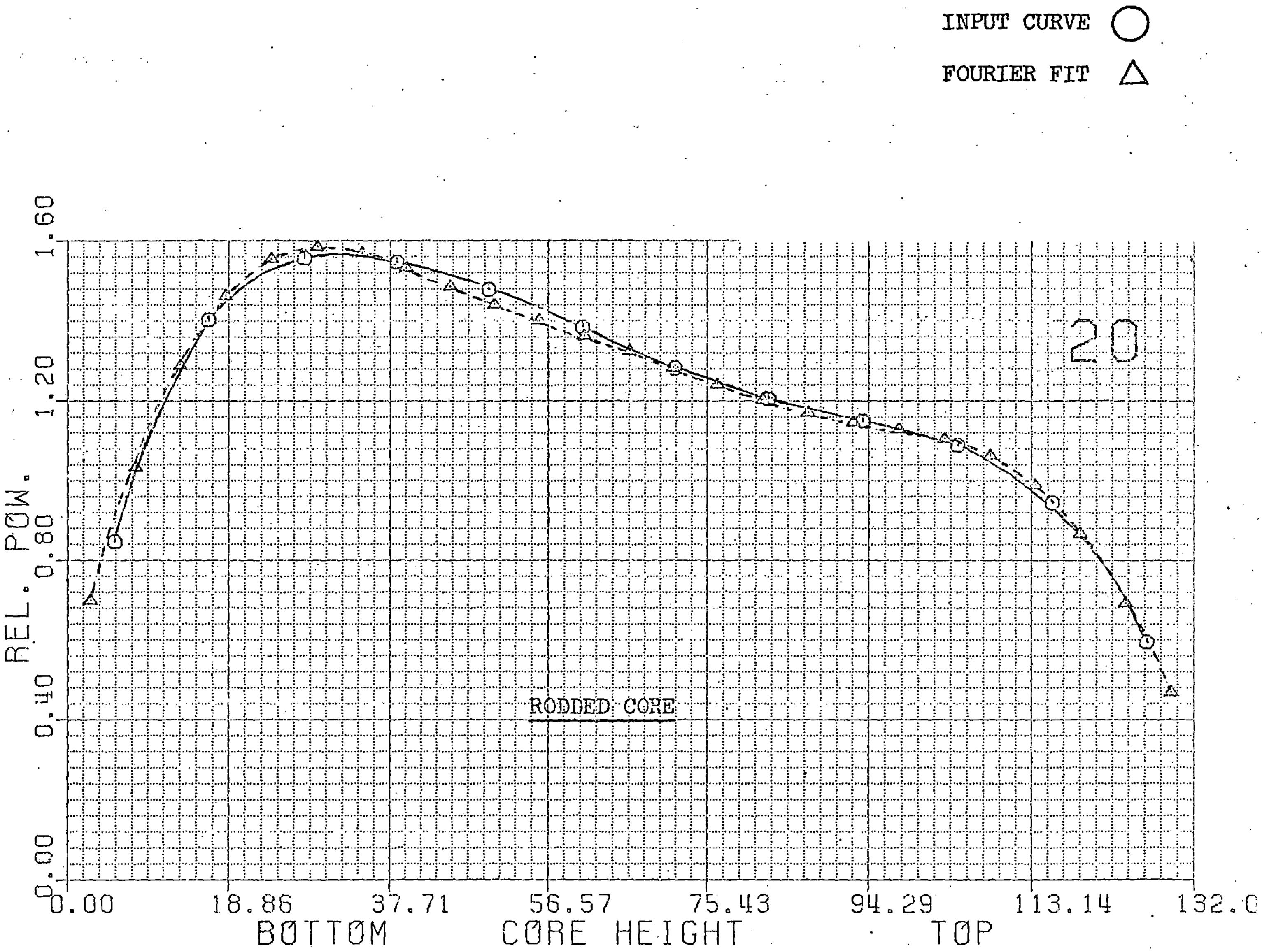

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