

## INFLUENCE OF THE ASSEMBLY CONFIGURATIONS ON THE FLOW INDUCED VIBRATIONS OF BWR FUEL ELEMENTS

C. CARMIGNANI, E. MANFREDI, S. REALE

*Istituto di Impianti Nucleari, Università di Pisa, Pisa Italy*

P. CERRETTI, A. FEDERICO

*Divisione Reattori Acqua Leggera, C.N.E.N., Roma, Italy*

### SUMMARY

One of the most important design features of a BWR (and PWR) fuel element is the assembly of the rod bundle itself, which is strongly influenced by the position, number and design of the spacer grids. A research program aimed to study systematically the influence of the assembly configurations on the vibrations of a typical BWR fuel element has been carried out by the Istituto di Impianti Nucleari of the University of Pisa and by the Divisione Reattori Acqua Leggera of CNEN which have worked at this program on cooperation terms.

The present paper reports about the final part of the experimental work performed in execution of the above mentioned program. This work consisted in a series of test runs carried out by means of a circulating water test loop realized for this purpose at Scalbatraio Laboratory of Istituto di Impianti Nucleari.

Each test run has been performed using one out of six different assembly configurations of 16 rods, 3 meters long representing, in 1:1 scale a part of a BWR fuel element. For this purpose three, five and seven spacer grids, either mounting a close fitting channel or not, have been used. The test runs have been carried out at flow velocities included between 1.5 and 8.5 m/sec. The fuel element has been fully instrumented by means of strain gauges mounted on the fuel rods, displacement transducers on the spacer grids and on the channel, accelerometers and pressure transducers on the loop tubes and on the test section.

The quasi stationary random signals obtained by each transducer have been recorded on magnetic tape and later digitalized to carry out spectral analysis by means of Fourier transform techniques.

It has been determined power spectral density and cross correlation functions and obtained phase and coherence informations, which have been used to evaluate vibration modes and root mean square amplitudes for each test configuration at the various flow velocities.

Later these results are compared with the prediction of the vibration behaviour of the fuel element, obtained from the available correlations given by other researchers, as well as from a new correlation formula devised for this scope.

## 1. INTRODUCTION

The mechanism of parallel flow induced vibrations has been extensively studied in recent years and the knowledges in this field have made marked progresses, particularly in the case of a single cylindrical slender bar.

The present status of knowledges about fuel assemblies behaviour, when subjected to parallel flow, is, however, less satisfactory.

Many important factors, which are absent in the case of a single rod, affect the dynamical behaviour of a fuel assembly; amongst them it has to be duly considered the influence of design, number and position of the spacer grids. Furthermore the vibration behaviour of BWR fuel assemblies is obviously affected by the channel, which surrounds the fuel rods bundle; either channel stiffness and amount of clearance between spacer grids and channel walls appear to have a marked influence, although it is difficult to take them properly into account in a theoretical approach to the problem.

The present work is therefore aimed to give some more insight about the influence of the assembly configurations of a BWR fuel element on its parallel flow induced vibrations.

The fuel element, which has been tested, is composed by 16 rods only; however it is supposedly apt to simulate the fluid elastic behaviour of the inner parts of larger fuel elements.

Since the scope of this research is to investigate the effects of assembly configurations, it has been used water flow at room temperature, circulating in a non-pressurized loop.

During each run as many as 20 or 22 signals have been simultaneously recorded; because the physical processes involved are mainly of the random type, spectral and correlation analysis of the experimental data are important aspects of the work performed. A computer program developed for this purpose has been used.

## 2. THE FUEL ELEMENT

The experiments have been carried out on a typical BWR fuel element (see Fig. 1); it is composed by 16 rods of about 15 mm external diameter and 2950 mm long; the fuel rods are manufactured in Zircaloy 2 and their inner diameter of 13,8 mm is slightly larger than the diameter of the uranium oxide pellets impiled inside them. Rod weight is about 4,35 Kg.

Most of the rods are pinned at both ends, as they are connected to the upper and bottom plates in the usual way; 4 of them are threaded and act as tie rods; one rod is segmented and it sustains the spacer grids, which accomply with the square matrix geometry of the 4 x 4 rod bundle; the minimum distance between rod surfaces is about 4,3 mm. The outer transversal dimension of the fuel element, measured at the spacer grids external surfaces is 79,4 mm. The spacer grid tested is shown in Fig. 2.

The fuel rod bundle is enclosed into a AISI 302 square channel 3000 mm long, which has an internal dimension of 80 mm and its wall is 2 mm thick. The minimum clearance between spacer grids and channel walls is therefore about 0,3 mm.

As it will be later exposed, the fuel element has been tested in six different assembly configurations, which are illustrated by Fig. 1.

## 3. EXPERIMENTAL RIG

### 3.1 - Basic experimental arrangement.

The Fig. 3A shows the scheme of the test loop. The fluid flow is composed by water at room temperature. The test loop is provided with a set of centrifugal pumps and the flow velocity is regulated by means of a system of valves;

the measurement of the flow velocities is performed by a set of Venturi meters.

### 3.2 - Test section.

The test section is illustrated by Fig. 3B; it is composed by a "perspex" square section shroud with bolted flange connections; the inner dimension of the shroud is 86 mm. It enables to perform experiments either with or without channel, keeping the flow through the rods at certain given values. The test section is long about 3000 mm, and at both ends it is connected to the upper and bottom plates clamping mountings. The test section is insulated against mechanical or fluid flow oscillations by means of a pair of damping rubber pipe joints and by a set of shock insulating mountings. The flow passes through a grid which lessens to a minimum flow periodical turbulence.

The fuel element is mounted inside the test section; its coaxial position is assured by the upper and bottom mountings, which realize a clamping-like restraint at both ends.

### 3.3 - Experiments.

Six series of test runs have been performed, each for one of six different assembly configurations (See Fig. 1).

The six tested configurations are characterized by the presence of the channel or by its absence; three, five or seven almost equally spaced grids have been assembled (See Fig. 1). For each configuration four test runs have been performed with the duration of 20 minutes each; during the four runs the calculated flow velocities inside the spaces between adjacent inner rods have been kept at the following values: 1.5, 2.5, 3.5 and 6 m/sec.

### 3.4 - Instrumentation.

During each test run it has been performed rod motions measurements by means of a set of eight semiconductor strain gauges placed at given points (See Fig. 4) of two inner rods.

The rod bundle motion has been measured by means of inductive displacement transducers, acting in orthogonal pairs on the surfaces of three spacer grids (See Figg. 2 and 4).

During the test runs performed in the channel-mounted configuration another displacement transducer has been used acting on the walls of the channel; a further transducer detected "perspex" shroud motion.

A set of pressure transducers has been placed in three different positions along the test section, to detect far field pressure fluctuations.

Accelerometers were placed on the pipes of the test loop and on the test section itself, to detect mechanical vibrations from external sources.

The signal from each transducer has been filtered and amplified, and it has finally been registered on a magnetic tape recorder, for further computer aided processing. The filters have been set in such a way, so that frequencies in a range comprised between 1 Hz and 200 Hz only have been analyzed.

The computer program, which has been used for this purpose, has been already described by A. Federico and P. Grillo [1] in a paper presented to 1st SMIRT Conference.

## 4. EXPERIMENTAL RESULTS

### 4.1 - Vibration modes and amplitudes.

The evaluation of power spectral densities and the analysis of amplitude and phase correlation between signals from different transducers have allowed

to estimate vibration modes and frequencies. As it may be expected the analysis confirmed the fact that the vibration of the fuel element present itself as a random superimposition of natural vibration modes.

In the assembly configurations without channel the amplitudes of first mode vibrations are by far the largest ones, and account for almost the total motion of the fuel assembly; the other natural modes give gradually lesser contributions.

In the assembly configurations with channel, natural vibration modes are scarcely recognizable; moreover it appears that maxima amplitudes of the rods bundle may correspond to higher frequencies. The whole assembly (i.e.: rods bundle plus channel) vibrates with small amplitudes at a frequency of its own.

It appears that the nominal amount of clearance between spacer grids and inner surfaces of the channel reduces itself to nihil in some places and at random. This fact completely modifies fuel assembly vibration behaviour.

Fuel assembly motions have been mainly detected by means of displacement transducers, acting on some of the spacer grids; their measurements have been checked by strain measurements on two inner rods. For the assembly configurations without channel, and for the power vibration modes, which surely correspond to a motion of the whole fuel assembly, there is a fair agreement between grid displacement and strain measurements; this fact points out a high degree of coupling between rod and assembly vibrations. For higher vibration modes there is less agreement between such measurements, as there is less coupling between rod and assembly motions; a limit case is represented by  $(N + 1)$  mode - where  $N$  is the number of the equispaced grids - since in this type of motion spacer grids almost coincide with rod vibration nodes.

#### 4.2 - Effect of assembly configurations.

Fuel element vibration amplitudes are much more influenced by assembly configurations than vibration frequencies are.

Amplitudes reduce in a marked way when more spacer grids are used and are even more influenced by the presence of a close fitting channel, which encloses the rods bundle. On the contrary it may be assumed that vibration frequencies differ relatively little from one assembly configuration to another, the differences being however more marked for the first mode.

The first vibration frequency seems to be slightly influenced by flow velocity also or, more probably, by vibration amplitudes; it appears that fuel assemblies have a non linear vibration behaviour, mainly of the soft-spring type.

In the case of the experiments without channel, some interesting informations about the effect of the different assembly configurations on fuel element vibrations, are obtained by means of a study of two main vibration modes. They are respectively the first vibration mode, which is a typical motion of the whole assembly, and the  $(N + 1)$  mode, which corresponds to an almost pure rod motion, with little or no motion of the spacer grids. Figg. 5 and 6 illustrate the variation of root mean square amplitudes versus flow velocity for different assembly configurations.

Existing correlation, which may be utilized to evaluate fuel element vibration amplitudes have been confronted with experimental results, as it is shown in Figg. 5 and 6.

Vibration amplitudes of the whole assembly and of the rod  $(N + 1)$  mode have been evaluated by means of the Paidoussis' [2] and Reavis' [3] correlations. Euratom [4] correlation has been used to evaluate rod motion amplitudes only.

In the case of the whole assembly, rods bundle stiffness and damping ratio have been previously evaluated by means of vibration tests in air and still water; to forecast  $(N + 1)$  mode amplitudes it has been considered a rod length equal to the distance between adjacent spacer grids.

It has to be said that in this latter case some of the rod parameters are quite out of the range considered by Paidoussis [2].

For the assembly configurations with channel it has not been possible to study vibration behaviour in such a way, as it depends from the actual contact situation between grids and channel, which varies at random from one experiment to another. Rods bundle maxima amplitudes for 5 grids configuration with channel is illustrated in Fig. 5. It has to be said that these amplitudes do not necessarily correspond to the first mode nor to the grid in mid-span. Rod motion, corresponding to the  $(N + 1)$  mode beforehand described, is illustrated by Fig. 6. The lesser degree of freedom of spacer grids apparently reduces the amplitudes of this motion too.

## 5. CONCLUSIONS

The present work has been mainly aimed to give a better knowledge about fuel element vibration behaviour when different assembly configurations are used and to evaluate the reliability of existing correlations to forecast vibration amplitudes.

It appears that vibration behaviour is strongly influenced by the presence of the channel. This is probably due to the fact that the nominal clearance between channel walls and spacer grids reduces to nihil in some places, following to unpredictable assembly actual conditions.

Regarding amplitude correlations, Paidoussis' and Reavis' only allow to take into account assembly parameters; however it is of critical importance the proper evaluation of some data, as hydraulic diameter etc., about which it is necessary to make some assumptions. However they are useful in the case of fuel assemblies without enclosing channel, while in the case of fuel assembly with close fitting channel, a really reliable correlation is still lacking.

## ACKNOWLEDGMENT

The authors most sincerely thank Mr. F. Borgiani and Mr. V. Pazzi of CNEN without whose cooperation this work should not have been possible.

## REFERENCES

- [1] FEDERICO, A. and GRILLO, P., "Fuel Rod Vibrations Induced by Coolant Flow" 1st SMIRT Conference - Berlin (1971).
- [2] PAIDOUSSIS, M.P., "The Amplitude of Fluid Induced Vibrations of Cylinders in Axial Flow" Chalk River. Nucl. Lab. USAEC AECL 2225 (1965).
- [3] REAVIS, J.R., "Vibration Correlation for Maximum Fuel Element Displacement in Parallel Turbulent Flow" Nuclear Science and Engineering: 38, 63-69 (1969).
- [4] BASILE, D., FAURE', J. and OHLMER, E., "Experimental Study on the Vibrations of Various Fuel Rod Models in Parallel Flow" Nuclear Engineering and Design 7, 517-539 (1968).

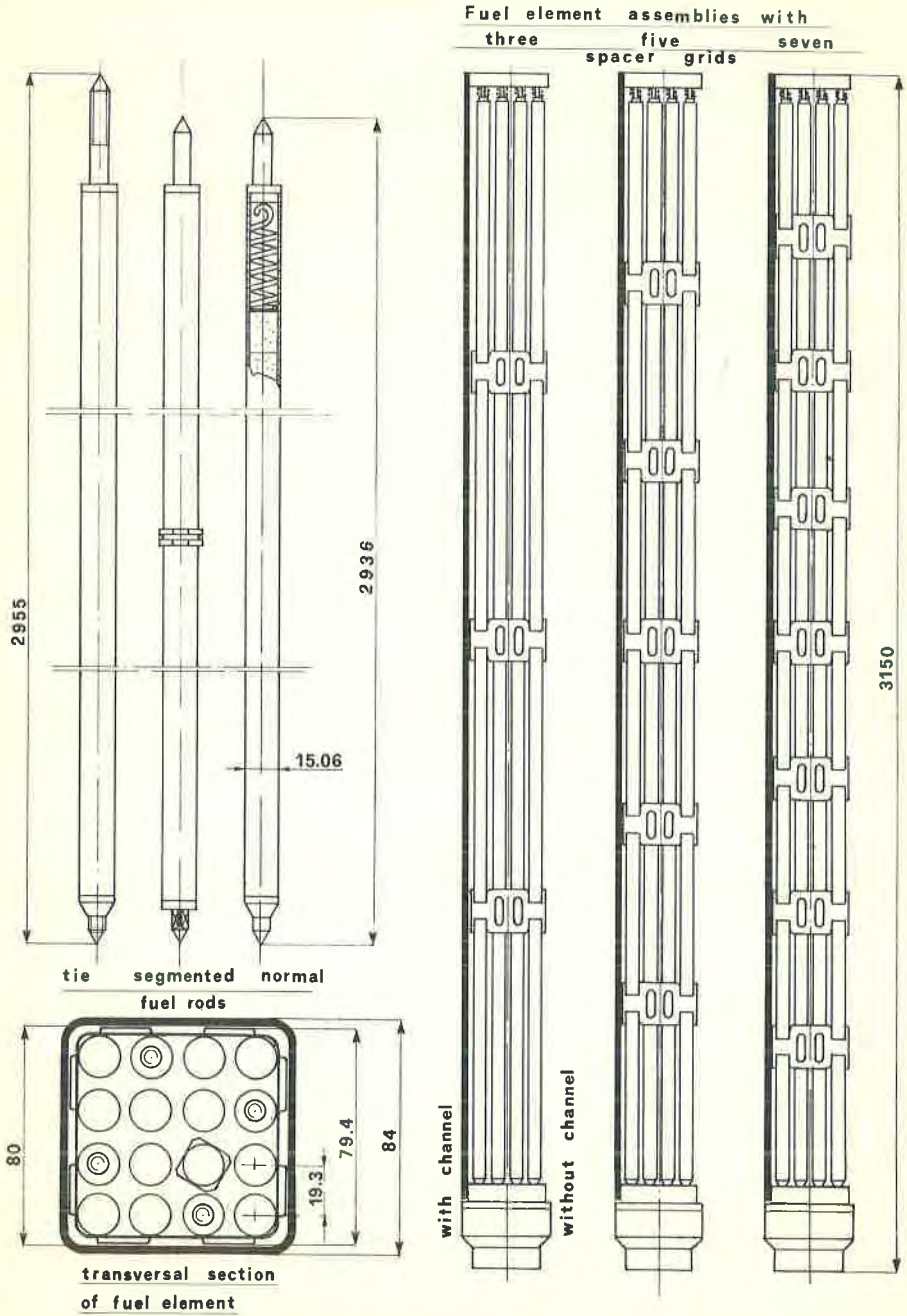


Fig. 1 The fuel element

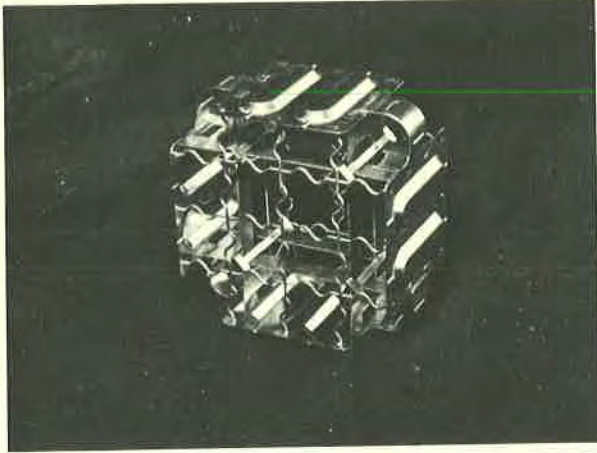


Fig. 2    Spacer grid

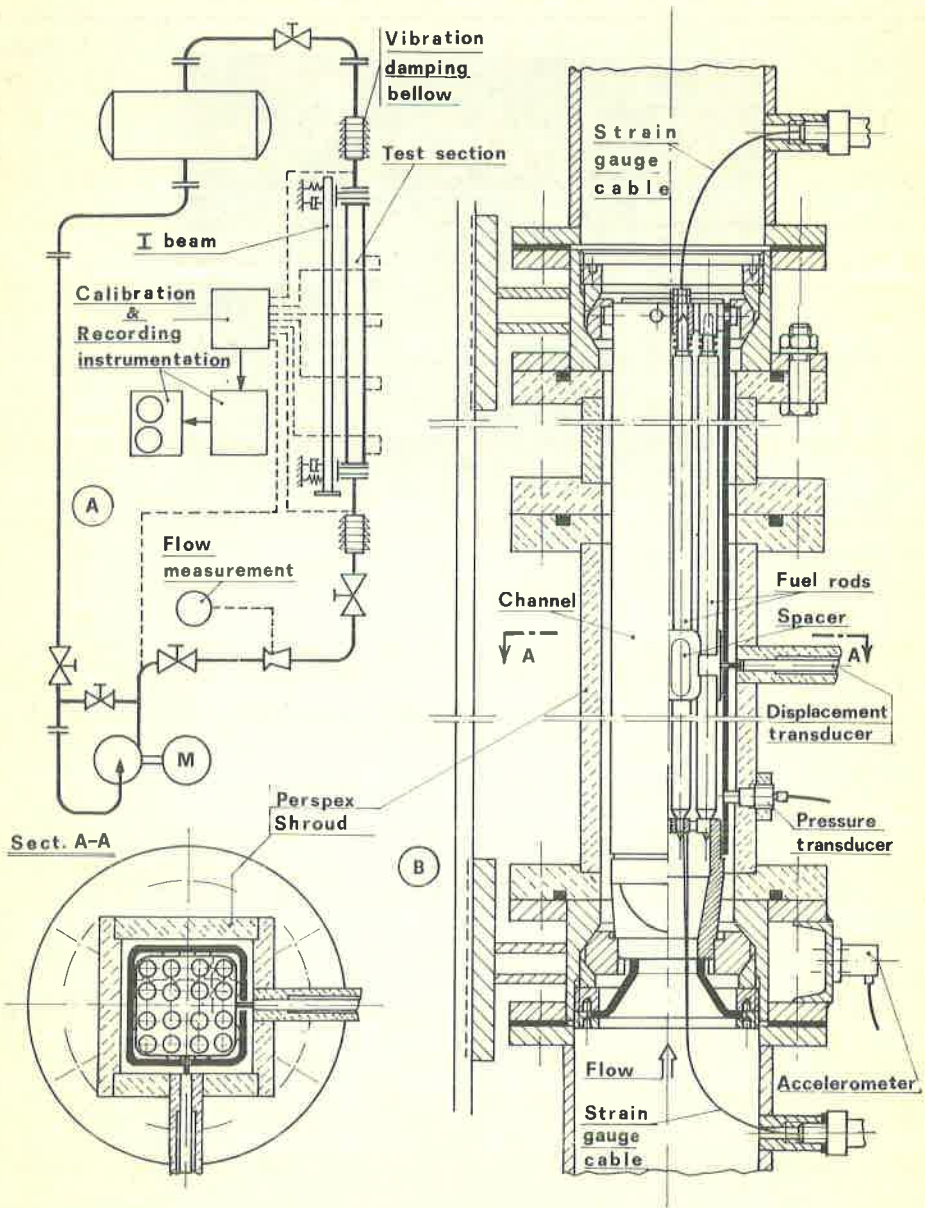


Fig 3 Experimental rig

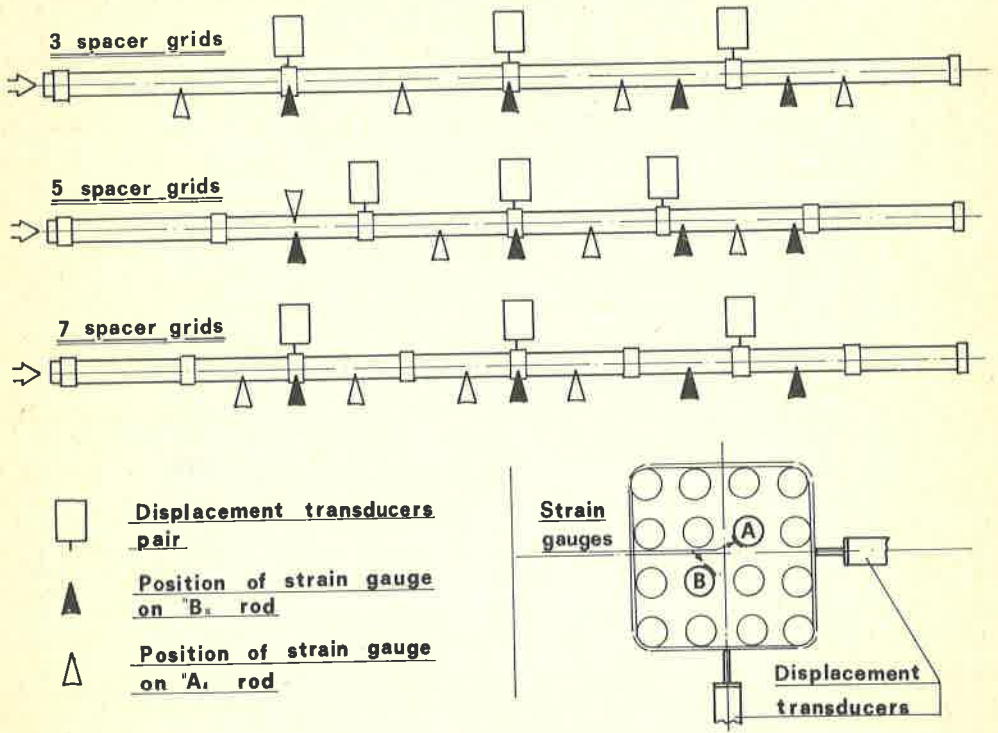


Fig. 4 Instrumentation transducers

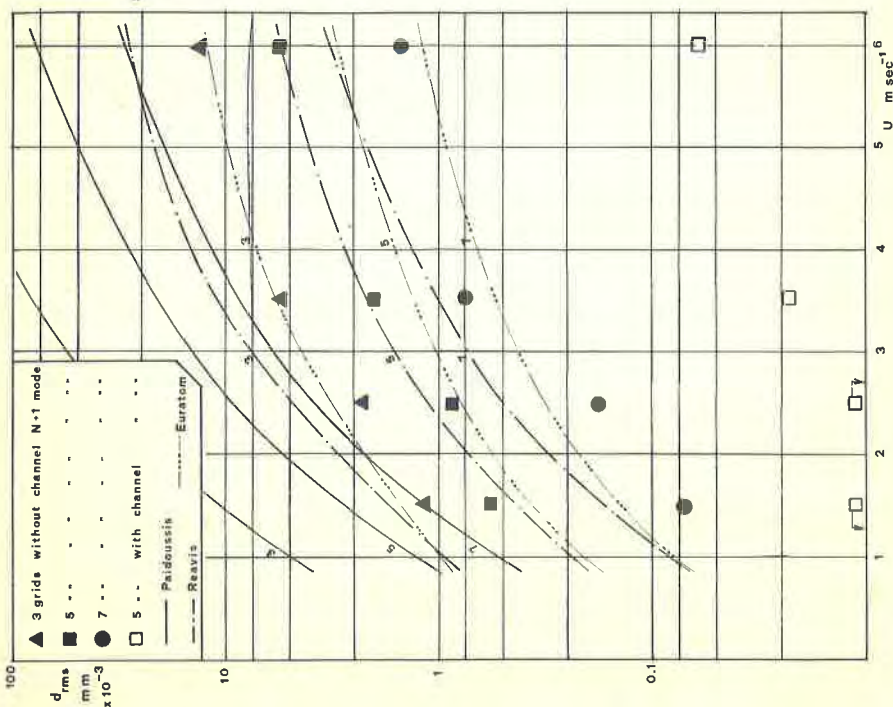


Fig. 5 Amplitudes of assembly vibrations

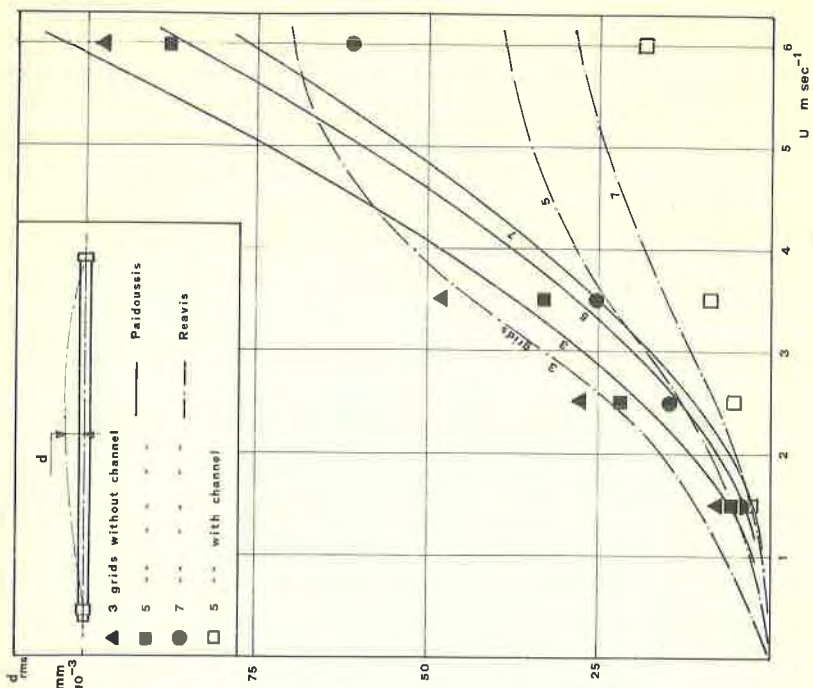


Fig. 6 Amplitudes of single rod ( $N+1$ ) mode vibrations